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THE REFLECTING POWER OF VARIOUS METALS.

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INTRODUCTION.

THE present observations are the result of an attempt to obtain a more thorough knowledge of the optical properties of the metals used in incandescent lamps. Several other elements on the border line between the metals and non-metals not heretofore examined are included, since the data are of general interest.

In a paper on the radiation constants of metals[1] attention was called to the fact that all the pure metals thus far examined have the common property of a low reflecting power in the ultra-violet and in the visible spectrum which rises more or less abruptly to very high values beyond 2μ in the infra-red, and that it is therefore not unreasonable to assume that the unexamined metals, such as tungsten and osmium, have this same property. This follows from the fact that all the members of a group of chemically related substances have similar physical properties. As will be noticed on a subsequent page, this assumption of a low reflectivity in the visible spectrum has been verified to a degree far beyond expectation.

[1] Bulletin Bureau of Standards, 1908, v, p. 339. See also this Bulletin, 1907, ii, p. 470, for illustration of the reflectivities of various metals.

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Since the reflectivity of metals is a smooth and continuous function of the wave-length in the infra-red, there is no reason for expecting these (heretofore) unexamined metals (tungsten, tantalum, etc.) to behave otherwise. Their spectral energy curves must therefore be smooth and continuous in the infra-red (no indentations or protuberances), and experimental curves showing such indentations are to be regarded with suspicion as to the accuracy of the observations.

It is difficult to show experimentally this selective emission in other than colored metals (*e.g.* gold and copper) by means of emission spectra, and since the emissivity in the short wave-lengths appears to have only a small temperature coefficient it is possible to gain some knowledge of the emissivity of the metal at high temperatures by determining its reflectivity at low temperatures. That it is permissible to apply data obtained at low temperatures to the same substance operated at high temperatures follows from the recent work of Hagen and Rubens [2] in which it is shown that for wave-lengths less than 4μ the optical constants of metals vary but slightly, if at all, with change in temperature, which is the region of the spectrum of interest in the question of the selective emission of incandescent lamps with metal filaments. We have therefore a positive qualitative proof of the much discussed and much overworked application of "selective emission" to explain the high luminous efficiency of the tungsten lamps. As will be noticed in the appended illustrations, the selective emission must lie in the visible spectrum. Here the emissivity is almost 50 p.c. (for tungsten) while in the infra-red it is only from 4 to 10 p.c. that of an ideal radiator, or "black body."

In the present experiments a fluorite prism, a mirror spectrometer, and a new vacuum bolometer were used. The unknown metal was compared with a new silvered glass mirror of which the reflecting power is known. The absolute value of the reflectivity of the unknown was obtained by multiplying the observed reflectivity by the reflectivity of silver given in Table II (data from Hagen and Rubens).

A Nernst glower was used as a source of radiation, which

[2] Hagen and Rubens, Phys. Zeitschrift, 1910, xi, p. 130; Verh. Phys. Gesell., 1908, x, p. 710.

permitted making observations in the extreme blue and at 10μ where the fluorite prism is almost opaque. Since the glower is very narrow it is necessary to have a very accurate adjustment of its images, reflected from the two mirrors upon the spectrometer slit, so as to avoid a systematic error in the reflectivity. The observations in the infra-red were further verified by using a Nernst "heater" instead of the glower. In the blue and beyond 8μ in the infra-red the accuracy is of the order of 2 to 3 p.c., while in the intervening region the accuracy is of the order of 1 per cent. There is no difficulty in obtaining high accuracy since we are only concerned with ratios of two numbers (galvanometer readings) which are of nearly the same value, and which are subject to the same errors of observation. In view of the physical nature of the material, and especially of the size of the specimens obtainable, and also of the indirect comparison with silver, it would be illusory to attempt to attain a higher accuracy for the absolute values. This is especially true of tungsten and molybdenum in which the mirror surface was ground upon one face of a rectangular prism of the pure metal, 20 x 6 x 6 mm. on an edge, kindly prepared for us by the General Electric Company. The narrowness of the specimen does not permit the grinding and polishing of an optically plane surface. The dimensions of the tantalum mirror were 15 x 10 x 1 mm.; it was prepared by Siemens and Halske and was optically plane and highly polished. The close agreement between the observed reflectivity of tungsten and molybdenum at 12μ and the theoretical value obtained from a knowledge of the electrical conductivity is therefore to be regarded as somewhat accidental. The angle of incidence of the light upon the mirrors was from 12° to 15° which is sufficiently small to be considered normal incidence and hence the loss by absorption (100-Reflectivity) is a measure of the emissivity of the metal.

From his observations on the optical constants (the refractive index, n, and extinction coefficient, k,) at 0.579μ Wartenberg[8] computed the reflecting power of various metals, some of which are included in the present paper. It will be noticed in Table I that the results obtained by the two methods are in excellent agreement.

[8] Wartenberg, Verh. Deutsch. Phys. Gesell., 1910, xii, p. 105.

TABLE I.

Substance	Reflecting power	Substance	Reflecting power
Manganese	63.5 p.c.	Tungsten	48.6; 51*
Chromium	69.7; 55*	Palladium	65.0
Vanadium	57.5; 57.5*	Rhodium	78.3; 77.5*
Tantalum	43.8; 45*	Platinum	72.5
Niobium	41.3	Iridium	74.6; 75*
Graphite	22.3; 23*	Silicon	35.7; 32*

* Observations by W. W. C.

It will be noticed that even in the visible spectrum the same magnitude of the reflectivity is to be found within a group of metals; for example, in the platinum group the reflectivity does not fall below 70 per cent., while in the chromium group the reflectivity centres about the 60 per cent. point. However, only beyond 12μ is this relationship true in general.

TUNGSTEN.

The area of the mirror examined was 5 mm. x 17 mm. This specimen was made from the pure material, which is somewhat brittle and did not permit a polished surface perfectly free from pores, except in the centre. This causes a slight scattering for wave-lengths up to 3μ (see discussion under graphite).

In Fig. 1 it will be noticed that the reflectivity of tungsten rises abruptly from a low value of 50 per cent. in the yellow to 89 per cent. at 2.5μ beyond which point it increases gradually to 96 per cent. at 10μ. This is a characteristic of pure metals.

Hagen and Rubens [4] have shown that for long waves (greater than 12μ) the absorption (100-Reflectivity) of a metal may be computed from its electrical conductivity, by means of the formula,

$$100\text{-}R = \frac{36.5}{\sqrt{c\lambda}},$$

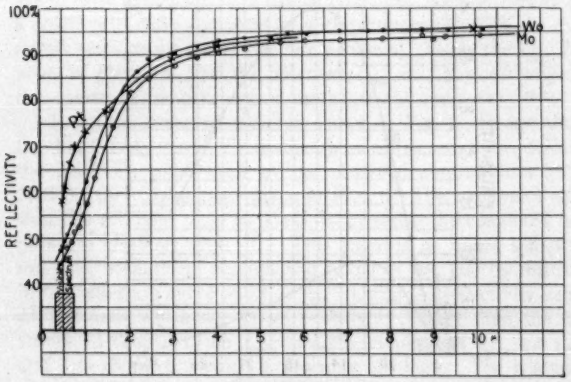
where R is the observed reflecting power, c is the reciprocal of the resistance, in ohms, of a conductor 1 mm. long and 1 sq. mm. in cross-section, and λ = wave-length in $\mu = 0.001$ mm.

The specific resistance of a squirted rod (hence probably not so pure as the mirror material) of tungsten 20 cm. long and

[4] Hagen and Rubens, Ann. der Phys., 1903 (4), xi, p. 873; Coblentz, Bulletin Bureau of Standards, 1907, ii, p. 470.

1.2 mm. in diameter was determined by Mr. J. H. Dellinger to be 0.000,0069 at 21.8° C. or 3.99 times that of copper. The sample of tungsten, upon which the reflectivity observations were made, had a specific resistance of 0.000,0063 at 21.5° C., or 3.66 times that of copper. Its density was 10 (true value about 19 or 20) which indicates that there were hollow spaces along the axis of prism of metal, which was about 2.5 cm. long, and had been broken from a much longer rod. At one end of this specimen there was a small cavity, but it was not possible to tell how

FIG. 1.

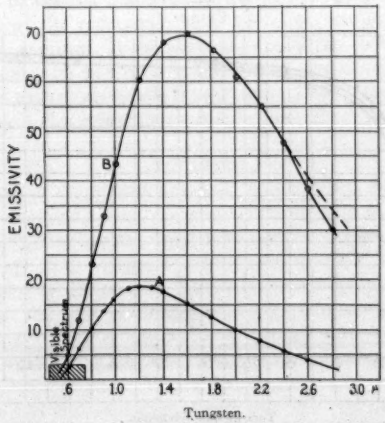


Tungsten, molybdenum.

far it extended along the central axis of the specimen. This would cause a higher resistance than the true value. Recent determinations by Fink and by Parani indicate a specific resistance of about 0.000,005 for annealed tungsten. From the specific resistance of this sample of tungsten the computed reflectivity, from the aforesaid formula using $\lambda = 12\mu$ is 97.3 per cent., while the value obtained by extrapolating from 10μ is 96.3 per cent. As already stated, this is in closer agreement than is to be expected from the observations, and from the size of the mirror employed. It may be noticed in Table II that the infra-red reflectivity of tungsten is the same as that of platinum, and in the visible it is the same as that of steel. For a perfectly polished

surface, free from pores, the reflectivity of tungsten would be somewhat higher out to 2μ, because of the elimination of the diffuse reflection which obtained in the present sample. (See graphite, which gives an extreme case of diffuse reflectivity.) The results show that in the previous investigation of the radiation constants of metals, it was permissible to assume that the same emissivity function obtains as in platinum, with, of course, different numerical values of the constants.

FIG. 2.



Tungsten.

In Fig. 2, curve *A*, is given the spectral energy curve of a new 110 volt, 32 candle-power tungsten lamp when on a normal operation of 55 watts. The mean value of the radiation constant for this lamp was previously computed (see foot-note 1) to be about $a = 6.5$, the variations in the individual computations being rather large. A new spectrometer calibration has just been computed which is more accurate than the one then employed. The new computation of this radiation constant is not sufficiently different from the old one to warrant a revision of the data then published, although the individual computations are in closer agreement. The new value of the $\lambda_{max} = 1.225\mu$ (old $\lambda_{max} = 1.257\mu$) and the new $a = 6.2$,—the shift in the new calibration

curve being about 0.02μ toward the short wave-lengths. On the basis of the new calibration curve the wave-lengths of maximum emission are too large by about 0.02μ. The radiation constants are also too large by 3 per cent. to 5 per cent. Since the individual computations vary by this amount, and since different samples of the metal filaments seem to be subject to variation, the old values are probably as trustworthy as would be the revised ones. The experimental data does not indicate a variation of the constant "a" with wave-length.

The reflection curve and the radiation constant ($a = 6.2$) are in close agreement with that of platinum. We are therefore in a position to make comparisons with platinum of which the radiation constants are fairly accurately known. Using the $\lambda_{max}\ T = 2620$ of platinum, and the observed $\lambda_{max} = 1.225\mu$ of tungsten, the operating temperature of the aforesaid lamp was 1870° C.

From the observed radiation curve A, Fig. 2, we can obtain the black-body curve B, at the same temperature by dividing the observed emissivities by the observed absorptivities (100-Reflectivity) of tungsten given in Fig. 1. The maximum emission lies at about $\lambda_{max} = 1.45\mu$ from which the computed temperature is about 1760° C. This value is no doubt somewhat too low, because no account was taken of the loss by diffusion in the reflection curve at 0.6 to 2μ. Using the reflectivity values of platinum which are in all probability higher than the true values of tungsten, the $\lambda_{max} = 1.38\mu$ in place of $\lambda_{max} = 1.45\mu$ and $t = 1860°$ C., which is probably too high. The computed values of a, from curve B, Fig. 2, vary from $a = 6$ to $a = 5.5$ while the experimental value for a "black body" is $a = 5$. This shows that curve B is not a true "black body" radiation curve. There are two evident reasons for this discrepancy. First, the observed curve A has not been corrected for absorption by the glass walls of the lamp, which would give an emissivity at 2.5μ somewhat as shown by dotted lines in Fig. 2. Second, the reflectivity is not known with sufficient accuracy at 1.5 to 2μ (because of diffuse reflection due to the fine pores in the specimen examined) where a small error in the reflectivity has a very large effect in the position of the maximum of the radiation curve. If it were not for this difficulty, this method could be used for estimating temperatures of metal filaments of known reflecting power (using perfect mir-

rors for determining the reflectivity), but of which it is impossible to measure the temperature directly. Since the emissivity and the reflectivity are functions of the refractive index and of the absorption coefficient, and since in considering the emissivity we are not concerned wth the scattering effect, it does not seem necessary to consider the question of the "blackening" of the radiation due to the porosity of the filament, so long as the size of the pores are of the same magnitude as the wave-length of the emitted light. This case seems to be different from the experiment in which the mechanical scratches, made in a strip of incandescent metal, show a higher emissivity than the outer surface. The present observations and those of Waidner and Burgess [5] seem to indicate that on "normal" operation the tungsten filament is at a temperature of 1850° C. to 2000° C.

TABLE II.

Wave-length in μ =.001 mm.	Silver	Platinum	Tungsten	Molybdenum	Iron	Tantalum (Watenberg's sample)	Chromium	Antimony	Magnesium	Graphite
0.40	84.0	48.0	47.0	44.0	.....	.....	.....	.....	.....	21.0
0.46	89.0	55.0	48.2	44.6	.....	.....	.....	.....	.....	22.0
0.5	90.0	58.4	49.3	45.5	55.0	38.0	55	.....	72.0	22.5
0.6	92.5	64.2	51.3	47.6	57.5	45.0	.....	53	73.0	23.5
0.7	94.2	69.0	54.0	49.8	59.5	.....	56	.....	.....	24.0
0.8	95.1	70.3	56.3	52.3	61.5	64.0	.....	.....	.....	25.0
1.0	96.4	73.0	62.3	58.2	65.0	78.0	57	55	74.0	26.8
1.2	97.2	75.0	68.2	63.6	68.5	84.0	.....	.....	.....	28.3
1.4	97.6	76.8	73.8	69.0	71.5	86.5	59	.....	75.0	30.0
1.6	97.8	78.0	78.0	74.2	74.3	88.0	61	58	.....	32.0
2.0	97.9	80.6	84.6	81.6	78.0	90.5	63	60	77.0	35.2
2.5	97.9	.....	89.2	85.5	81.5	91.6	66	.....	79.0	39.5
3.0	98.0	88.8	90.5	87.6	84.5	92.3	70	65	80.5	43.0
3.5	98.3	.....	92.0	89.2	87.5	92.8	.....	.....	.....	46.0
4.0	98.4	91.5	92.8	90.5	89.5	93.0	76	68	83.5	47.5
5.0	98.5	93.5	94.0	92.0	91.5	93.0	81	.....	86.0	50.5
6.0	98.6	.....	94.6	93.0	93.0	.....	85	70	88.0	52.0
7.0	98.6	95.5	95.1	93.3	94.0	93.5	.....	.....	91.0	53.5
8.0	98.8	95.1	95.6	93.7	94.0	93.8	89	.....	93.0	55.5
9.0	98.9	95.4	95.5	94.0	93.8	.....	92	72	93.0	57.5
10.0	99.0	95.9	95.5	94.5	.....	.....	93	.....	.....	59.0
12.0	98.9	96.5	96.3	95.5	.....	95.9	97	.....	.....	.....
∞	.....	.....	97.2*	97.3*	.....	95.7*	.....	.....	.....	.....

* Values computed from the electrical conductivity.

MOLYBDENUM.

The area of the mirror examined was 5 mm. x 17 mm. The reflecting surface had a very much higher polish than the sample of tungsten just described. To the eye it was apparent that the

[5] Waidner and Burgess, Bulletin Bureau of Standards, ii, p. 319.

molybdenum had a higher absorption than the tungsten mirror. This is illustrated in the bolometric comparison shown in Fig. 1 which indicates a reflectivity of only 46 per cent. in the yellow, which rises abruptly to 85 per cent. at 2.5μ beyond which point the reflectivity gradually increases to 95 per cent. at 10μ. The specific resistance of two samples of molybdenum wire, drawn to a uniform diameter, was determined by Mr. Dellinger. The wires were respectively 15 cm. and 20 cm. in length, 0.627 mm. and 0.815 mm. in diameter, and the corresponding specific resistance was 0.000,0064 and 0.000,0062 at 21.5°. This is about 3.6 times the resistance of copper and practically the same as that of tungsten. From this it appears that the reflectivity of molybdenum should be as high as that of tungsten at 12μ. The observations indicate the opposite condition. No systematic errors could be detected in the observations and the only explanation which can be offered at present is that the size of the reflecting surfaces was too small to establish a true absorption to a greater accuracy than 2 per cent. at 12μ. This, however, is not a large discrepancy when it is recalled that in some of the earlier work, using larger mirrors of known curvature, errors almost as large as these are on record.

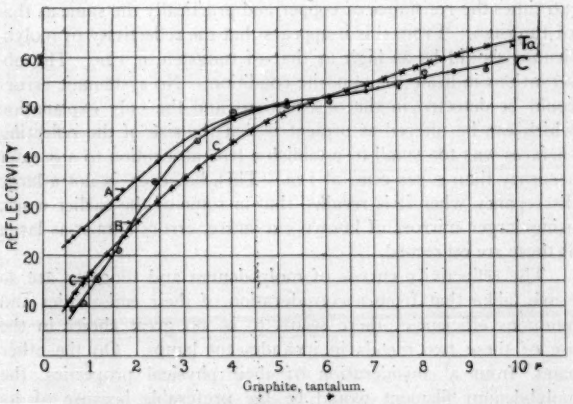
The reflectivity curves of molybdenum and tungsten are so nearly alike that from a consideration of their emissivities and luminous efficiencies there seems to be no great choice in the use of these two metals in incandescent lamps. On the other hand, from a consideration of their physical properties, the molybdenum filament would be the preferable because of its toughness and its ductility, in contrast with tungsten which is very brittle. Their melting points are high, and it is principally a question of overcoming certain physical weaknesses in the molybdenum in order to make it practical.

GRAPHITE.

Two samples of graphite were examined, the one being the natural mineral from Siberia. Its reflecting surface was 4 cm. x 5 cm. The second sample, curve *B*, Fig. 3, was a longitudinal section of a rod, 8 mm. in diameter, of Acheson's graphite. It could not be burnished free from pores which were rather large, and which caused a scattering of the radiation, out to 4μ in the infra-red. Beyond this point it reflects as highly as the natural

Siberian mineral, shown in curve *A*, Fig. 3. The natural mineral was very compact, but showed the rays and fibrous structure of the original plant or tree from which it was formed. It was burnished or "polished" on a semi-matte piece of plate glass. A thoroughly ground glass was too rough, while the smooth plate was found equally inapplicable. The partly ground glass seemed to hold just sufficient material to work into the softer parts without accumulating sufficient loose material which would roughen the surface. The glass plate was kept wet with

FIG. 3.



clean water and by the application of some pressure it was possible to prepare a very highly polished surface.

The reflectivity is 23 per cent. in the yellow, gradually increasing to 63 per cent. at 10μ. From this low reflectivity at 2μ in the infra-red there results a high emissivity, hence the graphatized carbon filament cannot have the same luminous efficiency as the tungsten lamp at the same temperature, although it has the higher emissivity in the visible spectrum.

TANTALUM.

The utilized area of the tantalum mirror was 9 mm. x 14 mm. In spite of its excellent polish, it showed an exceedingly low reflectivity throughout the spectrum, as compared with pure metals.

The curve *C*, in Fig. 3, represents three series of observations, using different adjustments, the measurements usually agreeing to one part in 100 to 200. In the visible spectrum the reflectivity is only 10 per cent. which gradually increases to 63 per cent. at 10μ. There is no indication of an approach to constant reflectivity, in the infra-red, such as obtains in pure metals. Subsequent correspondence with the maker showed that this surmise of an impure metal was correct. The surface was rendered impure by working and polishing which, by the action of gases, formed an exceedingly hard surface layer. From the writer's experience it appears that the ease with which a tantalum mirror becomes contaminated in polishing depends upon the previous history of the metal. For example, the regulus of tantalum obtained from Von Wartenberg [6] had never been rolled or hammered and it was found that, in polishing it, any contamination, such as for example the blackening caused by a film of oil, was easily removed. On the other hand, a film of oil on the mirror just described, which had evidently been worked down from a regulus (Fig. 3, *C*) formed a brown coating which was removed with great difficulty.[7] The rear side of this mirror was therefore ground flat on fine emery paper, which for the final polish was rubbed over with a layer of alcohol and graphite. By stroking lightly and lifting the mirror soon after the alcohol had entirely evaporated, a clean surface was produced which was almost free from scratches. The old surface, of which the reflectivity is given in Fig. 3, was so hard that it could not be polished by this method.

The contrast between the reflectivity of the old contaminated surface, and of the new surface, polished as just described, is shown in Fig. 4. Curve *C* gives the reflectivity of the new surface as produced by the fine dry emery paper, the scratches being quite deep. Curve *A* gives the reflectivity of the same mirror after giving it the final polish with graphite and alcohol when only very fine scratches remained. In the latter case the scattering is almost eliminated, and the reflectivity rises abruptly

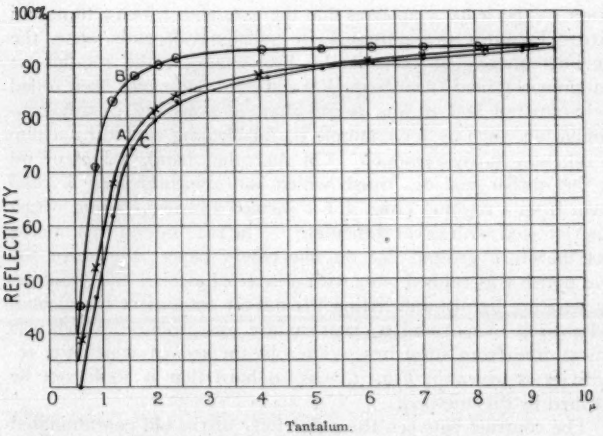
[6] Von Wartenberg, Verh. Phys. Gesell., 1910, xii, p. 121. He found that tantalum was not contaminated by polishing.

[7] See also a recent investigation by Parani, Vehr. Phys. Gesell., 1910, xii, p. 301, who likewise finds that tantalum is easily contaminated by gases.

from 39 per cent. in the yellow to 85 per cent. at 2.5μ beyond which point the rise is gradual to 94 per cent. at 9μ. The theoretical reflecting power, at 12μ, computed from the electrical conductivity is about 95.7 per cent.

Through the kindness of Dr. Von Wartenberg an opportunity was granted to examine the tantalum regulus mirror used by him in determining the optical constants in the visible spectrum. The area of surface which could be used was only about 2.5 mm. x 3

FIG. 4.



mm. and hence it was impossible to obtain the absolute reflectivities with high accuracy. There was no difficulty in obtaining the relative values for different parts of the spectrum, which is the point of most interest. The surface of the mirror was perfectly free from scratches. The reflectivity, which is shown in curve *B*, Fig. 4, rises even more abruptly to high values than was found in the first sample. In this respect, pure tantalum, zinc, and silver stand unique among the metals. Because of the steepness of the reflectivity curve, the emissivity of tantalum in the visible spectrum must be more selective than obtains in tungsten and molybdenum. Furthermore, since the reflectivity of *pure*

tantalum is higher than that of tungsten at 1 to 2μ it must have the higher luminous efficiency.

The reflectivity of the regulus of pure tantalum as observed by the two methods (Wartenberg computed R from the "optical constants") is about 45 per cent. in the yellow. The other mirror appeared much darker, so that the lower reflectivities as shown in Fig. 4 are to be attributed to impurities. The tantalum regulus appeared as bright as the prism of tungsten already described. The most casual observation shows that the tungsten filament has a much whiter metallic luster than a tantalum filament. This may be due to contamination in drawing the tantalum wire, especially if drawn with oil as a lubricant. It appears that in tungsten all the impurities can be driven off at high temperatures. This is not necessarily true of tantalum, which occupies an anomalous position in the scale of luminous efficiencies of metals.

From the observations of Waidner and Burgess, who found that the "normal" operating temperature of tantalum is about 2000° C., it is evident that its low luminous efficiency is not due to a low operating temperature, such as would be necessary with platinum.

Incandescent lamps of tungsten and osmium have an efficiency of about 1.25 watts per candle while for no apparent reason tantalum must be classified with graphitized carbon with an efficiency of about 2 to 2.5 watts per candle.

The foregoing data on the reflectivity of tantalum and graphite, Fig. 3, shows that this classification is consistent. The radiation constants of these two substances are almost the same (total radiation; tantalum proportional to the 5.3-power of temp.; graphitized filament proportional to the 5.1-power of temp.) and the manner in which they differ is in the right direction, since graphite is a non-metal. Hence, while it was somewhat contrary to expectation to find such a low reflectivity in the infra-red for impure tantalum this is not inconsistent with other data such as the radiation constants.

There seems to be a prevailing notion that the polish of the metal filament is of great importance, but it is not apparent how roughness or scratches can cause a "blackening" of the radiation by successive reflection within the cavities so long as the latter are of the order of the wave-length emitted. It is the

absorption coefficient and the refractive index that must be considered. This is especially conspicuous in tantalum filaments. When new they have a "brownish" lustre, while the filaments of old lamps are decidedly black. Similar filaments of osmium retain their gray appearance even after becoming crystalline. Under the microscope the crystalline tantalum filament appears much darker than tungsten, although the actual polish of the crystal surfaces of the latter is much higher. Some crystals appear as dark as highly polished jet or fine grains of stibnite which has a reflectivity of only about 35 per cent. This low reflectivity in the visible spectrum produces a high emissivity, but, contrary to the properties of the pure material, the reflectivity continues low (emissivity high) in the infra-red, which tends to lower the luminous efficiency.

The ideal solid illuminant must fulfil the conditions of a high operating temperature and a high emissivity in the visible spectrum. As shown in Fig. 1, of all the metals thus far examined, tungsten approaches nearest to the fulfilment of these conditions.

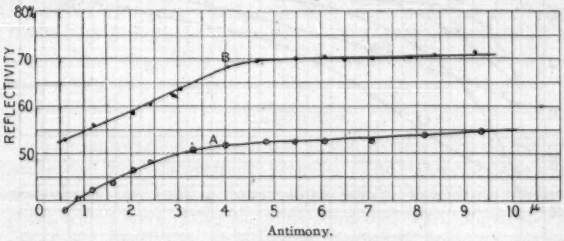
ANTIMONY.

It was found impossible to produce a perfect mirror of antimony, so that the absolute values obtained have little weight. Since the main object in the present work is to show the relative values of reflectivities in the visible as compared with the infra-red, the results obtained on several antimony mirrors are here recorded. As with all the other metals, larger surfaces, either plane or of known curvature, must be used for high accuracy in the absolute values.

Two samples of antimony were examined, the one being a mirror (5 mm. x 17 mm.) polished upon a cleavage plane of a large crystal of the metal, the other being a mirror formed in vacuo by cathode disintegration. The reflectivity of the polished cleavage piece is shown in curve *A* of Fig. 5. The reflectivity is low, due to the presence of numerous large-sized pores which resulted in the polishing. Two cathode mirrors were also examined. The first one contained small holes caused by dust particles on the glass surface which seemed to permit radiation from the rear surface of the glass (2 mm. in thickness) to return on its path, thus causing a wavy reflection-curve with maxima of about 65 per cent. at 1.2μ, 2.5μ, and 4μ, and minima of 55 to 60 per

cent. at 2μ, 3.3μ, and 6μ beyond which point the reflectivity increased gradually to 68 per cent. at 9μ. On removing the rear mirror surface these maxima and minima were destroyed. A second mirror (5 mm. x 17 mm.), free from dust holes, and with the rear surface of glass free from metal, was examined, the data being plotted in curve *B* Fig. 5. The reflectivity rises from 53 per cent. in the yellow to a fairly uniform value of 72 per cent. at 9μ. In view of the difficulty in producing a mirror, which is free from carbon, by the cathode discharge, and in view of the fact that the mirror seemed darker than one would expect, judging from the appearance of the crystals, it seems probable that the reflectivity is somewhat higher than here recorded. However, in view of the fact that antimony departs considerably from the true metals, the low reflectivity throughout the spectrum is prob-

FIG. 5.



Antimony.

ably to be expected, as will be noticed presently in several other metals which lie on the borderline between the electrical conductors and the insulators.

In conclusion, it may be added that cathode mirrors of antimony are easily produced in 5 to 7 minutes, by using a heavy current. The tendency is for one to continue the discharge for a longer period than this, with the resultant oxidation of the central part of the mirror. By using a residual atmosphere of hydrogen and a low current, excellent large-sized mirrors are produced in half an hour.

RHODIUM.

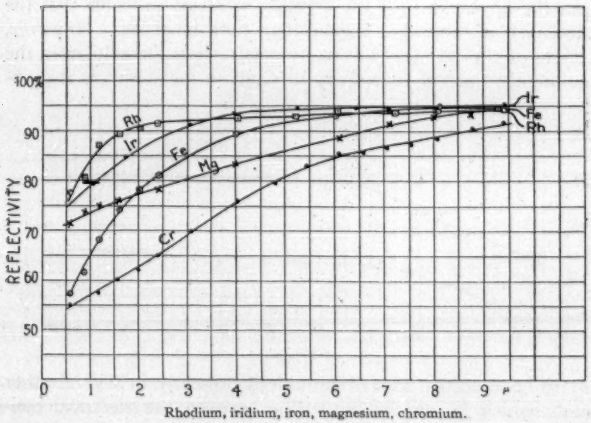
The sample examined was kindly loaned by Dr. Von Wartenberg. The area of the surface examined was 5 mm. x 5 mm. Several small blow-holes were present, which, with the smallness of the surface, did not permit high accuracy in the absolute values

of the reflectivities. The reflecting power, Fig. 6, rises abruptly from 77 per cent. in the yellow to 92 per cent. at 2.5μ beyond which point the rise is gradual to about 94 per cent. at 9μ.

IRIDIUM.

The mirror examined was a thick plate of the metal, which in the polishing had not been perfectly freed from pores which caused scattering. The reflectivity in the yellow was only 53 per cent., which increased to 75 per cent. at 2μ and to 90 per cent.

FIG 6



Rhodium, iridium, iron, magnesium, chromium.

at 8μ. This same plate was examined several years ago [8] when it had a finer polish. The reflectivity, Fig. 6, was found to increase from 79μ per cent. at 1μ to 95 per cent. at 99μ. Its reflectivity seems to be somewhat higher than platinum in the visible spectrum.

IRON.

The sample of iron examined is probably the purest obtainable. Its purity was 99.8 per cent. The chief impurities were 0.15 per cent. copper, 0.02 per cent. manganese, and 0.02 per cent. carbon. The sample took a high polish and reminded one

[8] Bulletin Bureau of Standards, 1907, ii, p. 470.

somewhat of palladium in its general appearances The reflectivity, Fig. 6, rises gradually with increase in wave-length and, throughout the spectrum, the values are about 2 per cent. higher than the values previously observed on steel by Hagen and Rubens.

MAGNESIUM.

The mirror examined had a surface of about 1.2 cm. x 2.5 cm. It was polished with considerable difficulty. A highly polished surface free from scratches was finally obtained by wet-grinding on fine emery paper, using tin oxide ("putty powder") and then (dry) polishing the surface on chamois skin with a little putty powder. This procedure prevented the formation of a film of oxide. However, the surface was not entirely free from blisters, so that the reflectivities are somewhat higher than recorded in Fig. 6. The reflectivity curve is somewhat different from that of a pure metal, especially of aluminum (see *Bulletin Bureau of Standards*, ii, p. 470). The alloy of aluminum and magnesium, magnalium, has a reflectivity curve which falls between these two metals.

CHROMIUM.

The sample of chromium was sawed from a lump of the metal made by the Goldschmidt process. The material was quite crystalline, but took a fairly high polish, excepting the usual pores which were rather large as compared with tungsten. The reflection curve, Fig. 6, increases gradually from 55 per cent. in the yellow to 91 per cent. at 9μ. Judging from previous experience with other metals it seems quite certain that, for a perfect mirror surface of non-crystalline material, the reflectivity of chromium would be higher in the yellow, as observed by Wartenberg. While part of the low reflectivity of chromium is no doubt due to diffuse reflection, out to 5μ, it is to be noted that this metal produces acid compounds, just as was observed with antimony, and in its general properties cannot be classed with the true metals. Hence its unusual reflection spectrum is to be expected.

VANADIUM.

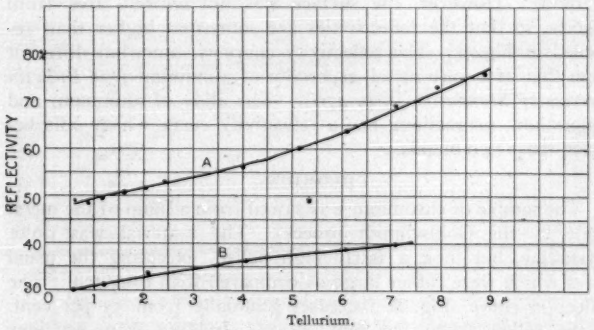
The sample examined was kindly loaned by Dr. Von Wartenberg. The surface was plane, highly polished, and the area examined was about 5 mm. x 5 mm.

The reflecting power, curve *C*, Fig. 8, rises gradually from 58 per cent. in the yellow to 92 per cent. at 9μ. In this respect it is very similar to chromium and iron, Fig. 6. This is to be expected since they fall in the same group in the Mendelejeff series.

TELLURIUM.

A knowledge of the reflectivity of tellurium is of interest because it occurs on the borderline between metals and non-metals and has a high electrical resistance. It is usually found in a highly crystalline state and is therefore difficult to polish a

FIG. 7.



surface free from pores. The reflectivity curve of such a mirror is given in curve *B*, Fig. 7. It is of interest only in showing the general trend of the reflectivities in various parts of the spectrum. The absolute values would be much higher if a correction could have been made for the loss by scattering caused by the roughness of the surface.

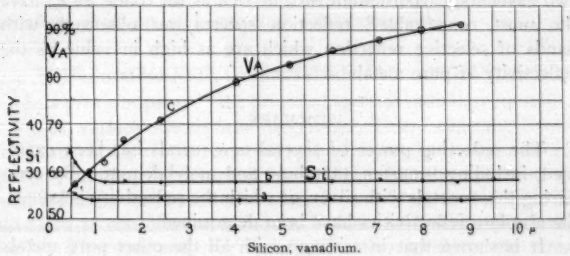
The best mirror used in the present examination was produced by the cathode discharge in hydrogen. It was found that unusually large-sized mirrors can be deposited in this manner, the time required being about half an hour. Thin deposits of tellurium transmit a reddish-brown light, which would indicate a low reflection beyond the red or a minimum reflection in the red. This is illustrated in curve *A*, Fig. 7, where at 0.8μ the

reflectivity, after repeated observations was found to be slightly less than in the yellow. While this might be due to the lack of knowledge of the true value of the reflectivity in the visible spectrum of the silver comparison mirror, the color of the transmitted light seems to indicate such a minimum.

The occurrence of a reflectivity minimum so far in the red is unusual in the true metals. However, the characteristics of tellurium are so different from the usual ones of true metals, that such an unusual reflecting power is probably to be expected.

The construction of a thermopile having large surfaces usually results in a sluggish instrument because of its great heat capacity. It has been suggested to deposit by cathode discharge

FIG. 8.



Silicon, vanadium.

two metals (for example, Te-Cu) upon some material which can afterwards be removed. These two films of metal are to overlap along one edge, which forms the active junction. The thermo-electric power of tellurium is very high, and in view of the ease with which a film of this metal can be deposited, it might prove satisfactory as a surface thermopile.

SILICON.

A knowledge of the reflectivity of this element is of interest because it belongs to the non-metals or insulators. Two samples were examined. The polishing was done on a fine grade of emery paper covered with a layer of tin oxide and a little graphite. The one sample, from Kahlbaum, curve *b*, Fig. 8, was quite homogeneous and took a very high polish, free from scratches. The second sample from The Carborundum Company, curve *a*,

Fig. 8, was less homogeneous, its hardness was greater and it took a poor polish. The crystals, as they come from the furnace, are of a bluish color, as was also true of the highly polished remelted sample here examined. This causes a high reflectivity in the visible (blue) spectrum, which decreases rapidly to a uniform value of 28 per cent. beyond 1μ in the infra-red. The lower value of 24 per cent. in curve *a* is due to the porosity and to the consequent diffuse reflection by this sample of silicon. From an examination of these two samples it appears highly improbable that the absolute values of the reflectivities, to 10μ in the infra-red, are much greater than 30 per cent. It was noticed in Fig. 3 that the reflectivity of graphite continues to rise gradually with increase in wave-length. The carbide of these two elements, carborundum SiC, as well as the oxide SiO_2, have the most remarkable[9] reflection spectra yet observed, with bands of selective reflection which are as high in value as the reflectivity of pure metals.

SUMMARY.

The reflecting power of several new metals has been examined, including tungsten, tantalum, and molybdenum. By comparing these metals with silver, of which the reflectivity is known, the absolute reflectivities have been determined.

It is shown that in common with all the other pure metals previously examined, the present series have a low reflectivity in the visible spectrum which increases rapidly to high values in the infra-red. The reflectivity curves of tungsten and of molybdenum are so nearly alike that from a consideration of their optical properties there is no great choice in the use of these two metals in incandescent lamps. Since molybdenum is tough and tungsten is brittle, it remains to be seen whether other physical difficulties can be overcome in the former metal, to enable its introduction as an illuminant.

The reflectivity curves show that the high efficiencies of the metal-filament lamps is due to their low reflectivity (true absorption and not diffuse reflection is meant) in the visible spectrum and to a high reflectivity in the infra-red.

In tungsten this results in an emissivity of almost 50 per cent.

[9] Bulletin Bureau of Standards, 1907, ii, p. 476.

in the visible spectrum, while in the infra-red the emissivity is less than 10 per cent. of an ideal radiator.

The ideal solid illuminant giving a high luminous efficiency must fulfil the condition of a high operating temperature, a high reflectivity (hence low emissivity) in the infra-red, and a low reflectivity (high emissivity,) in the visible spectrum. The pure metals, tungsten and molybdenum fulfil these conditions more exactly than any other known metals, excepting tantalum which as a lamp filament, however, does not have the optical properties of the samples described in this paper.

Thus far it has been impossible to obtain a large-sized sample of pure osmium, to determine its reflectivity.

In conclusion, the writer expresses his appreciation of the courtesy of Dr. Von Wartenberg in submitting his samples of tantalum, rhodium, and vanadium for examination.

NOTE I—COMMENTS ON RADIATION LAWS OF METALS.

In a previous paper [10] the principal spectral radiation constant, "a", of various metals was described. This "constant" was found to vary with the temperature and theoretical reasons were given to account for this variation. If the equation representing total radiation had been considered, $S = \sigma T^{a-1}$, then we would have had to consider the constant, "a", as well as the constant, "a". The constant $C_2 = \sigma\lambda_{max}T$ also involves the temperature, as well as other factors, so that "a" was the only constant that could be investigated, as described in the aforesaid paper. Assuming a value of $a = 6$, the radiation from platinum observed by Lummer and Kurlbaum,[11] shows a variation in the constant of total radiation from $\sigma = 8.24$ to $\sigma = 11.16$ for an increase in temperature of about 1275°. It seems apparent that "σ" cannot be considered constant, for it indicates the emissivity per unit area of a surface radiating under specific conditions. Now if those conditions vary, as is true of the metals in which the absorptivity (at any wave-length) is a function of the temperature, it would seem that the "a" cannot remain constant, but must increase with rise in temperature.

[10] Coblentz, Bulletin Bureau of Standards, 1909, v, p. 339. See p. 367 for a discussion of the radiation from platinum.

[11] Lummer and Kurlbaum, Verh. Phys. Ges., Berlin, 1898, xvii, p. 106.

The constant, a, in the Wien equation $E = c_1\lambda^{-a}e^{-\frac{c_2}{\lambda T}}$ and as tentatively assumed in the aforesaid computations, relates to a specific region of the spectrum; and irrespective of the writer's published data, experiments by others show that the emissivity of metals at any wave-length in the infra-red is affected by the temperature, *i.e.*, it has a temperature coefficient. But this is not all. At low temperatures the maximum emission, E_{max}, falls in the region of 3 to 6μ where the reflecting power at a given temperature is practically constant and we have to consider only the change in the radiation constant, a, due to the temperature coefficient of the reflectivity. At high temperatures the E_{max} falls in the region of 1.5μ (see Fig. 1) where at any given temperature the reflectivity changs rapidly with wave-lengths; and as it shifts toward the short wave-lengths the E_{max} must increase by a different law (from the Wien equation $E_{max} = BT^a$) from what it did when at 3 to 6μ. In the region of 1.5μ the temperature coefficient is small but the absorption (100-Reflectivity) varies rapidly with wave-length, while beyond 3μ the conditions are exactly the reverse. In both cases the emissivity, E_{max}, increases in a different manner than postulated by the simple radiation formulæ.

Now, from the Wien equation, $E = c_1\lambda^{-a}e^{-\frac{c_2}{\lambda T}}$, the radiation constant a is computed from the equation

$$a = \frac{\log E - \log E_{max}}{\log e - \frac{\lambda}{\lambda_{max}}\log e + \log\frac{\lambda}{\lambda_{max}}} \qquad \text{(Eq. 1)}$$

where E and E_{max} are the emissivities at the wave-lengths λ and λ_{max} respectively. It will be noticed that the temperature of the filament does not enter into this equation. From the most recent work of Hagen and Rubens (*Phys. Zeit.*, 1910, ii, p. 139) it appears that, in the region extending from the visible to 3μ, the temperature coefficient of emissivity is extremely small and the observed variations in a with temperature, as computed from the above equation, must be due to some other cause than a true temperature coefficient of emissivity. This cause is not difficult to find if we return to the reflectivity curves Fig. 1. At low temperatures, when λ_{max} falls in the region of 2μ, the E_{max} is but slightly affected by the temperature coefficient of emissivity, and since the reflecting power varies but slowly with the wave-

length, the E_{max} will be closely that required by the Wien equation ($E_{max}=B\ T^{a}$). At high temperatures when the λ_{max} falls in the region of 1.2μ, the E_{max} falls in the region where the reflectivity changes rapidly with wave-length, and consequently the value of E_{max} must increase at a higher rate than required by the equation $E_{max} = B\ T^{a}$. The difference between $\log E$ — $\log E_{max}$ (Eq. 1) must therefore be less than would otherwise be the case, due to this fact, and the decrease in a with temperature when computed from the above equation must necessarily follow, as observed.

From the reflectivity curves this seems a plausible explanation. Hence, an accurate value of a cannot be computed from the Wien equation as expressed in (Eq. 1). However, from the close agreement between the values of a of platinum by this and by more direct methods, it is evident that the errors resulting from the use of Equation 1 are not serious. The aforesaid work has shown in a fairly quantitative way that the constant a of tungsten is much higher than that of platinum and of carbon. The great suppression of the radiation of tungsten as compared with carbon in the infra-red is another proof of this. The Wien spectral energy curves, using different values of a, illustrate this same behavior, as may be easily verified by plotting the data given in Table I, *Bulletin Bureau of Standards*, vol. v, p. 347.

It seems evident that any spectral radiation formula which can be set up, must contain factors which will take into consideration not only the variation in emissivity with temperature, but also the variation in the absorptivity, which is a function of the wave-length and the temperature. Whether the constant a really varies [12] as found in my previous paper where the Wien equation was tentatively assumed, or whether the constant σ varies, or whether both vary, is not the all important question at this stage of our knowledge. The most important thing for the present is to get further experimental data, using wide strips of such metals, as platinum and tungsten, with a thermocouple to measure the temperatures. In this manner it is hoped to contribute more accurate data in the near future.

[12] As this paper goes to press, a short account of an investigation by Hyde, Elect. World, June 23, 1910, lv, p. 1654, has appeared in which the observed constancy of the ratios of the candlepowers of tungsten against carbon seems to show no temperature coefficient of emission, while for osmium

the ratios are not quite constant, indicating a probable temperature coefficient, which is in accordance with the results of other observers.

The danger of a too free indulgence in mathematical deductions, in which the physical facts are overlooked, is indicated by the derivation of two values of "σ" depending upon the radiation formula (Wien or Planck) employed. Experimentally there can be but one value of "σ" which is $\sigma = 5.3 \times 10^{-12}$ Watt per cm. The suggestion is made that the constant, C_2, might be considered variable, which is reasoning in a circle for $C_2 = a\lambda_{max}T$, experimentally, and since C_2 did not enter into the equations used by the writer, that constant was not discussed. Of course, C_2 varies if the above equation is true.

For metals, the physical facts are:

1. An extraordinary variation in their reflectivity, from the visible to about 2μ, beyond which point the reflectivity increases but slowly with wave-length.

2. A small temperature coefficient of emissivity from the visible to 3μ beyond which point the temperature coefficient increases rapidly with wave-length.

3. For the black body the position of maximum emission in the spectral energy curve shifts, with rise in temperature, toward the short wave-lengths by a fixed amount, because only the temperature enters the problem and $\lambda_{max}T = \text{constant}$. Furthermore, the height of the maximum emission increases by a fixed amount $E_{max} = BT^{\alpha}$. The total radiation progresses as $S = \sigma T^{\alpha}$. The constants "α" and "C_2" are concerned in the slope of the spectral energy curve, while "σ" defines the total emissivity per unit area of the radiator. In the pure metals the variation in E_{max} and λ_{max} will be affected (by variable amounts) by (1) and (2), and as already mentioned in the text, these formulæ, just mentioned, must be modified to take account of these facts.

It does not appear that we are contributing anything new to what was found in Germany 10 to 15 years ago when it was concluded that the Wien equation does not apply to the black body, in which the composition of the energy emitted is independent of the material forming the radiating enclosure; and if these spectral radiation formulæ do not apply to such a radiator, how can we expect them to apply (except perhaps at some one temperature, which does not appear very probable) to substances affected by the conditions (1) and (2) mentioned in the preceding paragraph.

In the paper just quoted doubt is expressed as to the accuracy of the emissivity ratios, for the region well within the visible spectrum, of carbon and tungsten lamps, operated on a color match (Bulletin Bureau of Standards, vi, p. 314, et seq.). Now, all depends upon what is meant by "well within the visible spectrum." Accurate spectrophotometric comparisons can be made to 0.68μ or 0.69μ. Abruptly at and beyond 0.7μ the photometric comparisons become more or less guess work; and yet the eye perceives this light. It may be noticed from the published curves that for a "color match" the ratios of intensities at a 0.7μ differ from those at 0.5μ by 1 to 2 per cent., which

would not be very convincing if we had no further data beyond this point. However, at 0.75μ the ratios differ by 5 to 6 p.c. from the values at 0.5μ and beyond this point the departure from the values at 0.5μ become larger with increase in wave-length, and the conclusion as to conditions at 0.7μ can be arrived at by extrapolating the incline line backward from 0.8μ. To admit that the line is rigidly horizontal throughout the visible spectrum to 0.75μ (to be inferred from the expressed doubt in the aforesaid paper), beyond which point it suddenly bends upwards, is to admit that there is a selective emission not very unlike that which obtains in the visible spectrum of incandescent gold and copper. The reflectivity curves of carbon and tungsten given herewith, show no indentations in the region of 0.7μ to 0.9μ, which would have to obtain, just as in gold and copper in the yellow, in order to give an increased emission in this region of the spectrum. The change in curvature in the graphs of Fig. 11, as shown in Bulletin Bureau of Standards, vi. p. 316, at 1.5μ to 2μ is probably to be expected, since the reflectivity of tungsten changes rapidly in this region of the spectrum, while the reflectivity of graphite increases gradually throughout this region.

WASHINGTON, D. C., May 28, 1910.

History of Portland Cement. (*Bull. Soc. d'Encour.*, cxiii, 3.)—The *Thon-Industrie Zeitung* gives a very interesting biography of Mr. J. C. Johnson, whom it terms the inventor of cement. He was born in London in 1811. Since 1836 he was manager of White's factory. In 1824 Joseph Aspdin, a mason of Leeds, patented a process for mixing an artificial hydraulic cement, which he called Portland cement, because it resembled the calcareous Portland stone; this product was used in 1828 for Brunel's Thames tunnel. A French patent, taken by Saint Léger in 1818, is almost identical with Aspdin's, except that the material was not subjected to so high a temperature and only produced an hydraulic lime. Johnson caused Aspdin's products to be analyzed and discovered, after numerous experiments, that the hydraulic properties of the cement were due to the chalk and to a clay very rich in silica. He finally arrived at the formula, 5 of dry chalk, 2 of damp clay, a composition similar to Pasley's, but Johnson heated to vitrification. In 1848 Johnson established a factory at Rochester, and his former chief bought all his production. Then he built factories at Cliff and at Gateshead, and ended by forming the company, J. C. Johnson & Co., with Aspdin as a partner. In 1854 he invented his intermittent vertical furnace, and in 1873 he built his third factory at Greenwhithe. When 43 years of age, Johnson learned French and German for his business needs. At 87 years of age he undertook to ride a bicycle, which he never abandoned.

PHYSICAL QUANTITIES CLASSIFIED IN THE ORDER OF THEIR DIMENSIONAL FORMULAS.

BY

CARL HERING.

HERETOFORE the dimensional formulas of physical quantities have been classified according to subjects; in such tables it becomes difficult to find the physical quantity when the dimensional formula is given, and still more so to find all those which have the same or nearly the same dimensions or are closely related. In the following tables all the physical quantities have therefore been arranged in the order of their dimensions, all those of the same dimensions being brought together, and those of nearly the same being close neighbors.

Numerous other matters of interest are also brought out by such a classification, which may sometimes be of use to those dealing with dimensional formulas, the relations of quantities, the search for new quantities, the search for new fundamental systems, etc.

The dimensional formulas are here arranged in groups. All the quantities containing the factor *length* (L) form the first group. In this group they are arranged in the order of the exponent of L, beginning with the smallest, that is, in the order L^{-3}, $L^{-\frac{3}{2}}$, L^{-2}, $L^{-\frac{1}{2}}$, L^{-1}, $L^{-\frac{1}{2}}$ ($L^0 = 1$ hence absent in this group), $L^{\frac{1}{2}}$, L, $L^{\frac{3}{2}}$, L^2, $L^{\frac{5}{2}}$, L^3. The letters are given preference in the following order, L, M, T, μ, κ, θ, α. In the second group they are similarly arranged in the order of the exponent of M, in the third in the order of that of T, and so on in each group, preference being always given to the other letters in the order just stated. Each quantity has been repeated in every group to which it belongs, thus making each one of the groups complete in itself.

The so-called "suppressed factors" μ and κ (whose dimensions are unknown) have been included, and together with θ for temperature and α for the plane angle, have been treated here

as auxiliary fundamental quantities. The dimension of an angle in this system is unity because $L \div L = 1$; this is a defect of this system and leads to such absurdities as torque=energy: the factor α has therefore been introduced here as a suppressed quantity in order to call attention to its presence.

The list of quantities was taken from the author's "Conversion Tables," p. 18–24, where they are classified, as usual, according to subjects and where their derivational formulas, symbols, etc. are also given; the latter are therefor not repeated here, as the present table is intended to supplement the usual ones.

Owing to the lack of knowledge concerning the dimensions of temperature, all the thermal quantities have here been based on four different fundamental conceptions. The first is based on the dynamical units, that is, on the formula of energy combined with a fourth fundamental unit representing temperature. The second is based on the thermal units; quantity of heat then is *mass* $\times$ *temperature;* in this system the specific heat of water is unity by definition and is therefore suppressed in the formula. In the third system volume is substituted for mass in the second. In the fourth system the author has suggested eliminating θ by defining temperature to be energy per unit of mass, that is, specific mass energy; the dimensions of temperature then are those of the square of a velocity. By substituting these dimensions of temperature for θ in the dynamical and the thermal systems (the first and the second) they all three give the same results for all the thermal quantities; this is not true of the thermometric system (the third one). This is an indication that the first, second and fourth systems are rational and the third is not; also that temperature is probably the square of a velocity; there are also other reasons for this same conclusion.

In general, whenever the dimensional formula is not definite, several of the probable ones are given, which accounts for the same quantity sometimes appearing with different formulas. The formulas for some of the less usual quantities were taken from the Smithsonian Physical Tables.

The abbreviations "elmg" and "elst" mean the electromagnetic and the electrostatic systems respectively.

CLASSIFIED ACCORDING TO LENGTH (L).

$L^{-3}M$	—	—		Density.
L^{-2}	—	—	α^2	Specific curvature of a surface.
"	—	T	μ^{-1}	Electric conductivity or specific electric conductance (elmg).
"	—	T^2	—	Coefficient of expansion (specific mass energy system).
"	—	"	μ^{-1}	Electric inductive capacity; dielectric constant; specific inductive capacity; (all elmg).
"	—	"	κ^{-1}	Permeability; specific magnetic inductive capacity; susceptibility; (all elst).
"	M	T^{-1}	—	Thermal emissivity or immissivity (thermal and specific mass energy systems).
$L^{-\frac{3}{2}}M^{\frac{1}{2}}$	"	"	$\mu^{-\frac{1}{2}}$	Current density, electric (elmg).
"	"	"	—	Surface density or electric displacement (elmg).
"	"	"	$\kappa^{-\frac{1}{2}}$	Flux density, magnetic; magnetic induction; intensity of magnetization; (all elst).
"	"	T	"	Electrochemical equivalent (elst).
"	"	"	$\kappa^{-\frac{1}{2}}\theta$	Coefficient of Peltier effect (elst).
L^{-1}	—	—	μ^{-1}	Reluctance or magnetic resistance (elmg).
"	—	—	α	Curvature or tortuosity.
"	—	T	μ^{-1}	Conductance, electric; admittance; susceptance; (all elmg).
"	—	"	κ^{-1}	Resistance, electric; reactance; magnetic reactance; capacity reactance or condensance; impedance; (all elst).
"	—	T^2	μ^{-1}	Capacity, electric (elmg).
"	—	"	κ^{-1}	Inductance; coefficient of self-induction; electrokinetic inertia; mutual inductance; permeance; magnetic capacity (all elst).
"	M	T^{-2}	—	Pressure or intensity of stress; modulus of elasticity; resilience.
"	"	"	θ^{-1}	Mechanical equivalent of heat (thermometric system).
"	"	T^{-1}	—	Conductivity, thermal (thermal and specific mass energy systems).
$L^{-\frac{1}{2}}M^{\frac{1}{2}}$	"	T^{-2}	$\kappa^{\frac{1}{2}}$	Current density, electric (elst).
"	"	T^{-1}	$\mu^{-\frac{1}{2}}$	Field intensity, magnetic; magnetizing force; (both elmg).
"	"	"	$\mu^{\frac{1}{2}}$	Flux density, magnetic; magnetic induction; intensity of magnetization; (all elmg).
"	"	"	$\kappa^{-\frac{1}{2}}$	Intensity of electric field; electromotive force at a point; (both elst).
"	"	"	$\kappa^{\frac{1}{2}}$	Surface density or electric displacement (elst).
"	"	—	$\mu^{\frac{1}{2}}$	Electrochemical equivalent (elmg).
"	"	—	" θ	Coefficient of Peltier effect (elmg).
"	"	—	$\kappa^{-\frac{1}{2}}$	Vector potential (elst).
$L^{\frac{1}{2}}$	$M^{-\frac{1}{2}}$	—	$\mu^{-\frac{1}{2}}$	Ionic charge (elmg).

$L^{\frac{1}{2}}$	$M^{\frac{1}{2}}$	T^{-2}	$\mu^{\frac{1}{2}}$	Intensity of electric field; electromotive force at a point; (both elmg).
"	"	"	$\kappa^{\frac{1}{2}}$	Field intensity, magnetic; magnetizing force; (both elst).
"	"	T^{-1}	$\mu^{-\frac{1}{2}}$	Current, electric; magnetomotive force; magnetic potential; (all elmg).
"	"	"	$\mu^{\frac{1}{2}}$	Vector potential (elmg).
"	"	"	$\kappa^{-\frac{1}{2}}$	Electromotive force or potential; difference of potential; coefficient of Peltier effect; (all elst).
"	"	"	" θ^{-1}	Thermo-electric height or specific heat of electricity (elst).
"	"	—	$\mu^{-\frac{1}{2}}$	Quantity of electricity; charge (elmg).
"	"	—	$\kappa^{-\frac{1}{2}}$	Flux, magnetic; magnetic lines of force; strength of pole; quantity of magnetism; electrokinetic momentum; (all elst).
L	—	T^{-2}	—	Acceleration, linear; intensity of attraction or force at a point.
"	—	"	κ	Reluctance or magnetic resistance (elst).
"	—	T^{-1}	—	Velocity, linear; thermal emissivity or immissivity (thermometric system).
"	—	"	μ	Resistance, electric; reactance; magnetic reactance; capacity reactance or condensance; impedance; (all elmg).
"	—	"	κ	Conductance, electric; admittance; susceptance; (all elst).
"	—	—	—	Length.
"	—	—	μ	Inductance; coefficient of self-induction; electrokinetic inertia; mutual inductance; permeance; magnetic capacity; (all elmg).
"	—	—	κ	Capacity, electric (elst).
"	M	T^{-3}	θ^{-1}	Conductivity, thermal (dynamical system).
"	"	T^{-2}	—	Force.
"	"	T^{-1}	—	Momentum or quantity of motion.
"	"	—	—	Inertia.
$L^{\frac{3}{2}}$	$M^{-\frac{1}{2}}$	T^{-1}	$\kappa^{\frac{1}{2}}$	Ionic charge (elst).
"	$M^{\frac{1}{2}}$	T^{-2}	$\mu^{\frac{1}{2}}$	Electromotive force; potential; difference of potential; coefficient of Peltier effect; (all elmg).
"	"	"	$\mu^{\frac{1}{2}}\theta^{-1}$	Thermo-electric height or specific heat of electricity (elmg).
"	"	"	$\kappa^{\frac{1}{2}}$	Current; magnetomotive force; magnetic potential; (all elst).
"	"	T^{-1}	$\mu^{\frac{1}{2}}$	Flux; magnetic lines of force; strength of pole; quantity of magnetism; electrokinetic momentum; (all elmg).
"	"	"	$\kappa^{\frac{1}{2}}$	Quantity of electricity, charge (elst).
"	"	—	$\kappa^{-\frac{1}{2}}a^{-1}$	Magnetic moment (elst).
L^2	—	T^{-2}	—	Temperature (specific mass energy system); latent heat (dynamical and specific mass energy systems).

L^2 — T^{-2} κ	Reluctivity; specific reluctance (elst).
" — " θ^{-1}	Mechanical equivalent of heat (thermal system).
" — T^{-1} —	Conductivity, thermal (thermometric system).
" — " μ	Resistivity or specific electric resistance (elmg).
" — — —	Surface.
" M T^{-3} —	Power or activity; electric power (elmg and elst); magnetic power (elmg and elst); rate of heat production; heat radiation; flow of heat; (all three dynamical and specific mass energy systems) flux of light.
" " " a^{-2}	Intensity of light.
" " T^{-2} —	Energy; work; vis-viva; impact; electric energy (elmg and elst); kinetic electric energy (elmg and elst); magnetic energy (elmg and elst) heat (dynamical and specific mass energy systems); quantity of light.
" " " θ^{-1}	Entropy (dynamical system).
" " " a^{-2}	Directive force (as in suspensions).
" " " a^{-1}	Torque; moment; couple.
" " T^{-1} "	Moment of momentum or angular momentum.
" " — a^{-2}	Moment of inertia.
$L^{\frac{5}{2}}$ $M^{\frac{1}{2}}$ T^{-1} $\mu^{\frac{1}{2}}$ a^{-1}	Magnetic moment (elmg).
L^3 $M^{-1}T^{-2}$ —	Gravitation constant.
" " — θ	Latent heat (thermometric system).
" — T^{-2} —	Force of a centre of attraction or strength of a centre.
" — $T^{-1}\theta$	Rate of heat production; heat radiation; flow of heat; (all thermometric system).
" — — —	Volume. Entropy (thermometric system).
" — — θ	Heat (thermometric system).

CLASSIFIED ACCORDING TO MASS (M).

L^3 $M^{-1}T^{-2}$ —	Gravitation constant.
" " — θ	Latent heat (thermometric system).
$L^{\frac{1}{2}}$ $M^{-\frac{1}{2}}$ — $\mu^{-\frac{1}{2}}$	Ionic charge (elmg).
$L^{\frac{3}{2}}$ " T^{-1} $\kappa^{\frac{1}{2}}$	Ionic charge (elst).
$L^{-\frac{3}{2}}M^{\frac{1}{2}}$ T^{-1} $\mu^{-\frac{1}{2}}$	Current density (elmg).
" " — "	Surface density or electric displacement (elmg).
" " — $\kappa^{-\frac{1}{2}}$	Flux density, magnetic; magnetic induction; intensity of magnetization; (all elst).
" " T "	Electrochemical equivalent (elst).
" " " " θ	Coefficient of Peltier effect (elst).
$L^{-\frac{1}{2}}$" T^{-2} $\kappa^{\frac{1}{2}}$	Current density (elst).
" " T^{-1} $\mu^{-\frac{1}{2}}$	Field intensity, magnetic; magnetizing force; (both elmg).
" " " $\mu^{\frac{1}{2}}$	Flux density, magnetic; magnetic induction; intensity of magnetization; (all elmg).
" " " $\kappa^{-\frac{1}{2}}$	Intensity of electric field; electromotive force at a point; (both elst).

$L^{-\frac{1}{2}}M^{\frac{1}{2}}$	$T^{-1}\kappa^{\frac{1}{2}}$		Surface density or electric displacement (elst).
" "	— $\mu^{\frac{1}{2}}$		Electrochemical equivalent (elmg).
" "	— $\mu^{\frac{1}{2}}$	θ	Coefficient of Peltier effect (elmg).
" "	— $\kappa^{-\frac{1}{2}}$		Vector potential (elst).
$L^{\frac{1}{2}}$ "	$T^{-2}\mu^{\frac{1}{2}}$		Intensity of electric field; electromotive force at a point; (both elmg).
" " "	$\kappa^{\frac{1}{2}}$		Field intensity, magnetic; magnetizing force; (both elst).
" "	$T^{-1}\mu^{-\frac{1}{2}}$		Current; magnetomotive force; magnetic potential; (all elmg).
" " "	$\mu^{\frac{1}{2}}$		Vector potential (elmg).
" " "	$\kappa^{-\frac{1}{2}}$	θ^{-1}	Thermo-electric height or specific heat of electricity (elst).
" " "	$\kappa^{-\frac{1}{2}}$		Electromotive force or potential; difference of potential; coefficient of Peltier effect; (all elst).
" "	— $\mu^{-\frac{1}{2}}$		Quantity of electricity; charge; (both elmg).
" "	— $\kappa^{-\frac{1}{2}}$		Flux, magnetic; magnetic lines of force; strength of pole; quantity of magnetism; electrokinetic momentum; (all elst).
$L^{\frac{3}{2}}$ "	$T^{-2}\mu^{\frac{1}{2}}$	θ^{-1}	Thermo-electric height or specific heat of electricity (elmg).
" " "	$\mu^{\frac{1}{2}}$		Electromotive force; potential; difference of potential; coefficient of Peltier effect; (all elmg).
" " "	$\kappa^{\frac{1}{2}}$		Current; magnetomotive force; magnetic potential; (all elst).
" "	$T^{-1}\mu^{\frac{1}{2}}$		Flux, magnetic; magnetic lines of force; strength of pole; quantity of magnetism; electrokinetic momentum; (all elmg).
" " "	$\kappa^{\frac{1}{2}}$		Quantity of electricity; charge; (both elst).
" "	— $\kappa^{-\frac{1}{2}}$	a^{-1}	Magnetic moment (elst).
$L^{\frac{5}{2}}$ "	$T^{-1}\mu^{\frac{1}{2}}$	a^{-1}	Magnetic moment (elmg).
$L^{-3}M$	— —		Density.
$L^{-2'''}$	T^{-1} —		Emissivity or immissivity, thermal (thermal and specific mass energy systems).
$L^{-1''}$	T^{-2} —		Pressure or intensity of stress; resilience; modulus of elasticity.
" " "	θ^{-1}		Mechanical equivalent of heat (thermometric system).
" "	T^{-1} —		Conductivity, thermal (thermal and specific mass energy systems).
— "	T^{-3} —		Illumination; brightness.
— " "	θ^{-1}		Emissivity or immissivity, thermal (dynamical system).
— "	T^{-2} —		Surface tension.
— "	T^{-1} —		Electric deposition (elmg and elst).
— " "	θ		Rate of heat production; heat radiation; flow of heat (all thermal system).
— "	— —		Mass; entropy (thermal and specific mass energy systems); capacity, thermal (dynamical, thermal, thermometric and specific mass energy systems).

—	M	—	θ	Heat (thermal system).
L	"	T^{-3}	θ^{-1}	Conductivity, thermal (dynamical system).
"	"	T^{-2}	—	Force.
"	"	T^{-1}	—	Momentum or quantity of motion.
"	"	—	—	Inertia.
L^2	"	T^{-3}	—	Power or activity; electric power (elmg and elst); magnetic power (elmg and elst); rate of heat production; heat radiation; flow of heat; (all three dynamical and specific mass energy system); flux of light.
"	"	"	a^{-2}	Intensity of light.
"	"	T^{-2}	—	Energy; work; vis-viva; impact; electric energy (elmg and elst); magnetic energy (elmg and elst); kinetic electromagnetic energy (elmg); heat (dynamical and specific mass energy system); quantity of light.
"	"	"	θ^{-1}	Entropy (dynamical system).
"	"	"	a^{-2}	Directive force (as in suspensions).
"	"	"	a^{-1}	Torque; moment; couple.
"	"	—	a^{-2}	Moment of inertia.
"	"	T^{-1}	a^{-1}	Moment of momentum or angular momentum.

CLASSIFIED ACCORDING TO TIME (T).

—	M	T^{-3}	—	Illumination; brightness.
—	"	"	θ^{-1}	Emissivity or immissivity, therm. (dynamical system).
L	"	"	"	Conductivity, thermal (dynamical system).
L^2	"	"	—	Power or activity; electric power (elmg and elst); magnetic power (elmg and elst); rate of heat production; heat radiation; flow of heat (all three dynamical and specific mass energy system); flux of light.
"	"	"	a^{-2}	Intensity of light.
L^{-1}	"	T^{-2}	—	Pressure or intensity of stress; resilience; modulus of elasticity.
"	"	"	θ^{-1}	Mechanical equivalent of heat (thermometric system).
$L^{-\frac{1}{2}}$	$M^{\frac{1}{2}}$	"	$\kappa^{\frac{1}{2}}$	Current density (elst).
—	—	"	a	Acceleration, angular.
—	M	"	—	Surface tension.
$L^{\frac{1}{2}}$	$M^{\frac{1}{2}}$	"	$\mu^{\frac{1}{2}}$	Intensity of electric field; electromotive force at a point; (both elmg).
"	"	"	$\kappa^{\frac{1}{2}}$	Field intensity, magnetic; magnetizing force; (both elst).
L	—	"	—	Acceleration, linear; intensity of attraction or force at a point.
"	—	"	κ	Reluctance or magnetic resistance (elst).
"	M	"	—	Force.
$L^{\frac{3}{2}}$	$M^{\frac{1}{2}}$	"	$\mu^{\frac{1}{2}}\theta^{-1}$	Thermo-electric height or specific heat of electricity (elmg).

$L^{\frac{1}{2}}$	$M^{\frac{1}{2}}$	T^{-2}	$\mu^{\frac{1}{2}}$	Electromotive force; potential; difference of potential; coefficient of Peltier effect; (all elmg).
"	"	"	$\kappa^{\frac{1}{2}}$	Current; magnetomotive force; magnetic potential; (all elst).
L^2	—	"	—	Temperature (specific mass energy system); square of a velocity; latent heat (dynamical and specific mass energy system).
"	—	"	κ	Reluctivity; specific reluctance (both elst).
"	—	"	θ^{-1}	Mechanical equivalent of heat (thermal system).
"	M	"	—	Energy; work; vis-viva; impact; electric energy (elmg and elst); magnetic energy (elmg and elst); kinetic electromagnetic energy (elmg); heat (dynamical and specific mass energy systems); quantity of light.
"	"	"	θ^{-1}	Entropy (dynamical system).
"	"	"	α^{-2}	Directive force (as in suspensions).
"	"	"	α^{-1}	Torque; moment; couple.
L^3	M^{-1}	"	—	Gravitation constant.
"	—	"	—	Force of a centre of attraction or strength of a centre.
$L^{-2}M$		T^{-1}	—	Emissivity or immissivity, thermal (thermal and specific mass energy systems).
$L^{-\frac{1}{2}}M^{\frac{1}{2}}$		"	$\mu^{-\frac{1}{2}}$	Current density (elmg).
$L^{-1}M$		"	—	Conductivity, thermal (thermal and specific mass energy systems).
$L^{-\frac{1}{2}}M^{\frac{1}{2}}$		"	$\mu^{-\frac{1}{2}}$	Field intensity, magnetic; magnetizing force; (both elmg).
"	"	"	$\mu^{\frac{1}{2}}$	Flux density, magnetic; intensity of magnetization; magnetic induction; (all elmg).
"	"	"	$\kappa^{-\frac{1}{2}}$	Intensity of electric field; electromotive force at a point; (both elst).
"	"	"	$\kappa^{\frac{1}{2}}$	Surface density or electric displacement (elst).
—	—	"	—	Frequency (elmg and elst).
—	—	"	κ	Conductivity or specific electric conductance (elst).
—	—	"	α	Velocity, angular.
—	M	"	—	Electric deposition (elmg and elst).
—	"	"	θ	Rate or heat production; heat radiation; flow of heat; (all thermal system).
$L^{\frac{1}{2}}$	$M^{\frac{1}{2}}$	"	$\mu^{-\frac{1}{2}}$	Current; magnetomotive force; magnetic potential; (all elmg).
"	"	"	$\mu^{\frac{1}{2}}$	Vector potential (elmg).
"	"	"	$\kappa^{-\frac{1}{2}}\theta^{-1}$	Thermo-electric height or specific heat of electricity (elst).
"	"	"	$\kappa^{-\frac{1}{2}}$	Electromotive force or potential; difference of potential; coefficient of Peltier effect; (all elst).
L	—	"	—	Velocity, linear; emissivity or immissivity, thermal (thermometric system).
"	—	"	μ	Resistance, electric; impedance; reactance; magnetic reactance; capacity reactance or condensance; (all elmg).

L	—	T^{m-1}	κ	Conductance, electric; admittance, susceptance; (all elst).
"	M	"	—	Momentum or quantity of motion.
$L^{\frac{3}{2}}$	$M^{-\frac{1}{2}}$	"	$\kappa^{\frac{1}{2}}$	Ionic charge (elst).
"	$M^{\frac{1}{2}}$	"	$\mu^{\frac{1}{2}}$	Flux, magnetic; magnetic lines of force; strength of pole; quantity of magnetism; electrokinetic momentum; (all elmg).
"	"	"	$\kappa^{\frac{1}{2}}$	Quantity of electricity; charge (both elst).
L^{3}	—	"	—	Conductivity, thermal (thermometric system).
"	—	"	μ	Resistivity or specific electric resistance (elmg).
"	M	"	a^{-1}	Moment of momentum or angular momentum.
$L^{\frac{5}{2}}$	$M^{\frac{1}{2}}$	"	$\mu^{\frac{1}{2}}$ a^{-1}	Magnetic moment (elmg).
L^{3}	—	"	θ	Rate of heat production; heat radiation; flow of heat; (all thermometric system).
L^{-2}	—	T	μ^{-1}	Conductivity or specific electric conductance (elmg).
$L^{-\frac{3}{2}}$	$M^{\frac{1}{2}}$	"	$\kappa^{-\frac{1}{2}}$	Electrochemical equivalent (elst).
"	"	"	$\kappa^{-\frac{1}{2}}$ θ	Coefficient of Peltier effect (elst).
L^{-1}	—	"	μ^{-1}	Conductance, electric; admittance; susceptance; (all elmg).
"	—	"	κ^{-1}	Resistance, electric; impedance; reactance; magnetic reactance; capacity reactance or condensance; (all elst).
—	—	"	—	Time; period (elmg and elst); time constant (elmg and elst).
—	—	"	κ^{-1}	Resistivity or specific electric resistance (elst).
L^{-2}	—	T^{2}	—	Coefficient of expansion (specific mass energy system).
"	—	"	μ^{-1}	Electric inductive capacity; dielectric constant; specific inductive capacity; (all elmg).
"	—	"	κ^{-1}	Permeability or specific magnetic inductive capacity; susceptibility; (both elst).
L^{-1}	—	"	μ^{-1}	Capacity (elmg).
"	—	"	κ^{-1}	Inductance or coefficient of self-induction; electrokinetic inertia; mutual inductance; permeance; magnetic capacity; (all elst).

CLASSIFIED ACCORDING TO MAGNETIC PERMEABILITY (μ).

L^{-2}	—	T	μ^{-1}	Conductivity or specific electric conductance (elmg).
"	—	T^{2}	"	Electric inductive capacity; dielectric constant; specific inductive capacity; (all elmg).
L^{-1}	—	—	"	Reluctance or magnetic resistance (elmg).
"	—	T	"	Conductance, electric; admittance; susceptance; all elmg).
"	—	T^{2}	"	Capacity (elmg).
—	—	—	"	Reluctivity; specific reluctance; (both elmg).
$L^{-\frac{3}{2}}M^{\frac{1}{2}}$		T^{-1}	$\mu^{-\frac{1}{2}}$	Current density (elmg).
"	"	"	— "	Surface density or electric displacement (elmg).
$L^{-\frac{1}{2}}$	"	T^{-1}	"	Field intensity, magnetic; magnetizing force; (both elmg).

$L^{\frac{1}{2}}$	$M^{-\frac{1}{2}}$	—	$\mu^{-\frac{1}{2}}$	Ionic charge (elmg).
"	$M^{\frac{1}{2}}$ T^{-1}	"		Current; magnetomotive force; magnetic potential (all elmg).
"	"	—	"	Quantity of electricity; charge; (both elmg).
$L^{-\frac{1}{2}}$	$M^{\frac{1}{2}}$ T^{-1}	$\mu^{\frac{1}{2}}$		Flux density, magnetic; intensity of magnetization magnetic induction; (all elmg).
"	"	—	"	Electrochemical equivalent (elmg).
"	"	—	" θ	Coefficient of Peltier effect (elmg).
$L^{\frac{1}{2}}$	" T^{-2}	$\mu^{\frac{1}{2}}$		Intensity of electric field; electromotive force at a point; (both elmg).
"	" T^{-1}	"		Vector potential (elmg).
$L^{\frac{3}{2}}$	" T^{-2}	"	θ^{-1}	Thermo-electric height or specific heat of electricity (elmg).
"	" "	$\mu^{\frac{1}{2}}$		Electromotive force; potential; difference of potential; coefficient of Peltier effect; (all elmg).
"	" T^{-1}	$\mu^{\frac{1}{2}}$		Flux, magnetic; magnetic lines of force; strength of pole; quantity of magnetism; electrokinetic momentum; (all elmg).
$L^{\frac{5}{2}}$	" "	"	a^{-1}	Magnetic moment (elmg).
—	— —	—	μ	Magnetic permeability; permeability or specific magnetic inductive capacity; susceptibility; (all elmg).
L	— T^{-1}	"		Resistance, electric; impedance; reactance; magnetic reactance; capacity reactance or condensance; (all elmg).
"	— —	— "		Inductance or coefficient of self-induction; electrokinetic inertia; mutual inductance; permeance; magnetic capacity; (all elmg).
L^2	— T^{-1}	"		Resistivity or specific electric resistance (elmg).

CLASSIFIED ACCORDING TO ELECTRIC INDUCTIVE CAPACITY (κ).

L^{-2}	— T^2	κ^{-1}		Permeability or specific magnetic inductive capacity; susceptibility; (all elst).
L^{-1}	— T	"		Resistance, electric; impedance; reactance; magnetic reactance; capacity reactance or condensance; (all elst).
"	— T^2	"		Inductance or coefficient of self-induction; electrokinetic inertia; mutual inductance; permeance; magnetic capacity; (all elst).
—	— T	"		Resistivity or specific electric resistance (elst).
$L^{-\frac{1}{2}}$	$M^{\frac{1}{2}}$ —	$\kappa^{-\frac{1}{2}}$		Flux density, magnetic; magnetic induction; intensity of magnetization; (all elst).
"	" T	"		Electrochemical equivalent (elst).
"	" "	"	θ	Coefficient of Peltier effect (elst).
$L^{-\frac{1}{2}}$	" T^{-1}	$\kappa^{-\frac{1}{2}}$		Intensity of electric field; electromotive force at a point; (both elst).
"	" —	"		Vector potential (elst).
$L^{\frac{1}{2}}$	" T^{-1}	"		Electromotive force or potential; difference of potential; coefficient of Peltier effect; (all elst).

$L^{\frac{1}{2}}$	$M^{\frac{1}{2}}T^{-1}$	$\kappa^{-\frac{1}{2}}$	θ^{-1}	Thermo-electric height or specific heat of electricity (elst).
"	"	—	"	Flux, magnetic; magnetic lines of force, strength of pole; quantity of magnetism; electrokinetic momentum; (all elst).
$L^{\frac{3}{2}}$	"	—	$\kappa^{-\frac{1}{2}}$ a^{-1}	Magnetic moment (elst).
$L^{-\frac{1}{2}}$	"	T^{-2}	$\kappa^{\frac{1}{2}}$	Current density (elst).
"	"	T^{-1}	"	Surface density or electric displacement (elst).
$L^{\frac{1}{2}}$	"	T^{-2}	"	Field intensity, magnetic; magnetizing force; (both elst).
$L^{\frac{3}{2}}$	$M^{-\frac{1}{2}}$	T^{-1}	"	Ionic charge (elst).
"	$M^{\frac{1}{2}}$	T^{-2}	"	Current; magnetomotive force; magnetic potential; (all elst).
"	"	T^{-1}	"	Quantity of electricity, charge (elst).
—	—	—	κ	Electric inductive capacity; dielectric constant; specific inductive capacity; (all elst).
—	—	T^{-1}	"	Conductivity or specific electric conductance (elst).
L	—	T^{-2}	"	Reluctance or magnetic resistance (elst).
"	—	T^{-1}	"	Conductance, electric; admittance; susceptance; (all elst).
"	—	—	"	Capacity (elst).
L^{2}	—	T^{-2}	"	Reluctivity; specific reluctance (elst).

CLASSIFIED ACCORDING TO TEMPERATURE (θ).

$L^{-1}M$		$T^{-2}\theta^{-1}$			Mechanical equivalent of heat (thermometric system).
$L^{\frac{1}{2}}$	$M^{\frac{1}{2}}$	T^{-1}	"	$\kappa^{-\frac{1}{2}}$	Thermo-electric height or specific heat of electricity (elst).
—	—	—	θ^{-1}		Coefficient of expansion (dynamical, thermal and thermometric systems).
—	M	T^{-3}	"		Emissivity or immissivity, thermal (dynamical system).
L	"	"	"		Conductivity, thermal (dynamical system).
$L^{\frac{3}{2}}$	$M^{\frac{1}{2}}$	T^{-2}	"	$\mu^{\frac{1}{2}}$	Thermo-electric height or specific heat of electricity (elmg.)
L^{2}	—	"	θ^{-1}		Mechanical equivalent of heat (thermal system).
"	M	"	"		Entropy (dynamical system).
$L^{-\frac{1}{2}}$	$M^{\frac{1}{2}}$	T	θ	$\kappa^{-\frac{1}{2}}$	Coefficient of Peltier effect (elst).
$L^{-\frac{1}{2}}$	"	—	"	$\mu^{\frac{1}{2}}$	Coefficient of Peltier effect (elmg).
—	—	—	θ		Temperature (thermal, thermometric and dynamical systems); latent heat (thermal system).
—	M	T^{-1}	"		Rate of heat production; heat radiation; flow of heat; (all thermal system).
—	"	—	"		Heat (thermal system).
L^{2}	M^{-1}	—	"		Latent heat (thermometric system).
"	—	T^{-1}	"		Rate of heat production; heat radiation; flow of heat; (all thermometric system).
"	—	—	"		Heat (thermometric system).

CLASSIFIED ACCORDING TO ANGLE (α).

$L^2\ M\ T^{-2}\alpha^{-2}$	Intensity of light.
" " T^{-2} "	Directive force (as in suspensions).
" " — "	Moment of inertia.
$L^{\frac{3}{2}}\ M^{\frac{1}{2}}$ — α^{-1}	Magnetic moment (elst).
$L^2\ M\ T^{-2}$ "	Torque; moment; couple.
" " T^{-1} "	Moment of momentum or angular momentum.
$L^{\frac{1}{2}}\ M^{\frac{1}{2}}$ " "	Magnetic moment (elmg).
L^{-1} — — α	Curvature or tortuosity.
— — T^{-2} "	Acceleration, angular.
— — T^{-1} "	Velocity, angular.
— — — "	Angle, plane.
L^{-2} — — α^2	Specific curvature of a surface.
— — — "	Angle, spherical.

CLASSIFIED ACCORDING TO NO-DIMENSIONAL QUANTITIES.

Number.....	Specific gravity. Specific heat (dynamical thermometric, thermal and specific mass energy systems). Mechanical equivalent of heat (dynamical and specific mass energy systems). Electric inductive capacity; dielectric constant; specific inductive capacity; inductance factor; (all elmg). Electric inductive capacity; dielectric constant; specific inductive capacity; (all elst). Efficiency; power factor; angle, plane; angle, solid.
Number $\times\mu^{-1}$.....	Reluctivity; specific reluctance; (elmg).
Number $\times\mu$.....	Permeability or specific magnetic inductive capacity; susceptibility; (both elmg).
Number $\times\kappa$.....	Electric inductive capacity; dielectric constant; specific inductive capacity; (all elst).

INTEGRITY OF TESTS OF METALS.

BY

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THERE is no subject of greater interest and importance in the metallurgical arts than that of testing metals. Upon the integrity of these tests rests the stability of all the immense modern structures composed of iron, steel, bronze and other metals; human life depends in many instances upon the reliability of tests made in the laboratories of 'coupons' cut from full size sections, in some cases, or from small bars,—usually cast attached to larger masses,—in other cases.

These coupons, or test-pieces, are supposed to fairly represent the average tensile and transverse strength, the ductility or resilience (*i.e.*, ability to resist shock), the micro-structure of the metal and, in a word, to reveal the true physical properties of the material entering into any given structure.

Have we arrived at a degree of perfection in the art of testing metals that enables us to rely with confidence upon such records? I fear not, and I purpose herein to give briefly a few of my reasons for this somewhat pessimistic view.

So far as the development of various machines for accurately testing the tensile strength, transverse strength, torsional strains, and so forth, of metals, is concerned, a very high degree of sensitiveness combined with accuracy, has been arrived at by many constructors of such apparatus, but if the specimens tested do not in all cases fairly represent the quality of the material in the mass the records may be, and often are, misleading.

My own investigations, extending over a period of nearly forty years, have convinced me that coupons or test-pieces do not always represent truly the strength, molecular structure, resilience, etc., of the material to which they may be attached

and to which they are supposed to conform closely in physical properties for the following reasons among others.

Metals in their pure state are not employed in engineering constructions, all are more or less heterogenous compounds, or alloys, and all alloys (with perhaps a single exception, viz., gold and copper) tend to 'segregate' or separate in the process of cooling from the liquid to the solid condition into richer and poorer alloys, one particular combination usually forming what is known technically as the 'eutectic.' For example the standard alloy of silver and copper (nine parts silver, one part copper) used for the silver coin of the United States Government and of many other nations, is, of course, prepared with the greatest care, and the molten metal is thoroughly stirred before it is poured into 'ingots.'

These ingots are made of the proper width and thickness to enable them to be rolled into strips from which the blanks or 'planchets' for the coin are punched. If an assay be made from chips or filings cut from the centre of a silver dollar and an assay also be made from chips cut from the periphery, they will not agree exactly; indeed cases have been known where the variation in 'fineness' actually exceeded the legal limit of 'tolerance' or allowance of variation from the standard of 'nine-tenths fine.'

This fact was proven by exhaustive investigations, made many years ago, which resulted in the abandonment of the old method of taking test-pieces by cutting chips from the ingots, or from the blanks, and substituting therefor what is known as the 'granulation test method.' After the melted alloy has been thoroughly 'rabbled' or stirred, two or more samples of the liquid metal are dipped out from the pot and poured into ice water in order to cool them instantly in the form of granules. Under these conditions there is not time for segregation to occur, and duplicate samples taken from the top and bottom of a crucible containing perhaps 7000 to 10,000 Troy ounces of coin metal will agree in fineness within a few thousandths of one per cent.

In the case of the standard gold alloy for coin (nine parts gold, one part copper) no precautions of this kind are needed, for the simple reason that this alloy does not segregate, and chips taken from the edge and from the centre of a double-eagle will

conform to the legal requirements, notwithstanding that they are very much more strict than in the case of silver coin.

An experience of twelve years as an assistant in the Assay Laboratory of the United States Mint (1868–1880) made me familiar with these refinements in metallurgical methods of testing that have been of inestimable value in my after life, which has been devoted to testing commercial metals. The knowledge thus gained has been practically applied in various ways in connection with cast-iron, steel and bronzes.

With respect to cast-iron it is no exaggeration to say that the rate of cooling of gray cast-iron exerts as important an influence in determining its physical properties as does variation of its chemical constituents within, of course, certain quite wide limits. If a wedge-shaped bar be cast of ordinary foundry iron, say six feet long, six inches wide, six inches thick at one end, and tapering in thickness to, say one-quarter inch thick, almost every grade of cast-iron may be found in the bar by nicking and breaking it into short sections, say six inches long each. At the thick end the fracture will be coarse grained or 'open' with very dark color due to the fact that almost all of the carbon is in the graphitic or 'free' condition. At the thin end the fracture will be fine grained and light in color because a considerable portion of the carbon will be chemically combined with the iron. If test-bars be cut from these different sections, it will be observed that the coarse-grained metal is very soft under the tool, while test-bars cut from near the thin end will be very hard to turn. Between these two extremes the metal will have intermediate degrees of hardness and of coarse grainedness.

If tensile tests be made from different portions of the casting, it will be found that the strength varies with the structure through an enormous range, as much as 100 per cent. gain often occurring in one portion over another. If the ordinary foundry iron used for the wedge-shaped casting be low in silicon (say 1 per cent. or under) the thin end of the wedge will be as white as silver, as hard as steel and as brittle as glass, because a large proportion of the carbon will then be in the combined form.

I have before me two test-bars of soft foundry iron used for casting light pulleys, poured from one small hand-ladle of

iron into companion bars of the same size, viz., 1 in. x 1 in. x 15 in.; one bar was cooled normally in the 'green' sand mold, the other was cooled very rapidly indeed. Both bars were broken transversely on an ordinary transverse testing machine, using a span of 12 inches. One bar, cooled normally, broke under a strain of 2000 pounds (round figures); the other, cooled rapidly, at 4000 pounds exactly. One-half of each bar was then used for tensile tests, being turned to the same dimensions and pulled upon a 100,000 pound hydraulic testing machine. The bar cooled normally showed tensile strength of 21,500 pounds per square inch. The bar cooled rapidly showed tensile strength of 37,000 pounds per square inch. These particular tests were made twenty-two years ago and the results have been corroborated many times since then, also valuable practical use has been made continuously from that time of the knowledge thus gained of the remarkable effect of controlling the cooling of castings of non-uniform sections.

In a paper giving some of the foregoing facts, read before the American Society for Testing Materials in 1903 published in their *Proceedings*, vol. iii, p. 216, the following conclusions were drawn:

"The rate of cooling of cast-iron from the fluid to the solid state is such an important factor in determining the physical properties of the metal, that it is just as necessary to know the dimensions of the test-bars as it is to know the chemical composition. For the same reason it is equally desirable that standard sizes of test-bars should be adopted, which would be suitable for different grades of iron."

It is pleasing to note that the American Society for Testing Materials has, through one of its sub-committees, been endeavoring to bring about uniformity of methods of testing, not only between different manufacturers in the United States, but also in Europe as well, with indications of a successful issue in time.

Castings of iron and other metals are frequently made for the Government as well as for private engineering firms under specifications which sometimes tax the ability of the founder to meet pretty stiff requirements as to strength. In the absence of any specific rules as to the method of molding the test-bars or coupons, or even as to their size, the temptation to a foundry foreman, who may have practical knowledge of

the facts here noted, to 'jockey' with the test-bars and thus insure that they will fully meet the requirements, is very great, and ought not in the interest of all to be continued longer.

There is still another method, now pretty well known, by which the transverse strength of cast-iron test-bars can be increased from 25 per cent., even up to nearly 50 per cent., without either rapid cooling of the metal or making any change in method of molding. Instead of simply brushing off the loose sand from the test-bars with a wire scratch-brush if they be placed in a 'tumbling barrel,' commonly employed in foundries for cleaning castings and tumbled about therein for a couple of hours, they will all gain largely in transverse strength due, it is thought partly, if not mainly, to the rapid release of 'cooling strains' caused by shocks, and it has long been known that iron-castings improve in strength with age, due to gradual release of internal strains. When these peculiar observations were first made known, the custom of cleaning the sand from test-bars in the tumbling barrel became very popular indeed and finally a few years ago the American Society for Testing Materials found it desirable to incorporate a special clause in its new specifications for cast-iron that test-bars must not be tumbled or otherwise subjected to mechanical shocks or vibrations before being broken. This was a gratifying tribute to the original discovery.

On the occasion of a visit to a large manufacturing establishment sometime before this restricting clause was adopted I noticed that all of the cast-iron transverse test-bars had been put through the tumbling mill 'to clean them' as I was informed by the boss.

With regard to test-bars for bronze castings, similar restrictions should apply in regard to cooling, for segregation occurs in all commercial bronzes, depending largely upon the rate of cooling from the liquid to the solid state. This segregation changes the molecular structure and affects the tensile strength of the metals. Coupons or test-pieces of bronze cooled much more rapidly than the castings to which they may be attached do not reveal the true character of the fracture, or the real strength of the metal. On the contrary they present to the eye a finer grained, more uniform metal and show abnormal strength in the testing machine. Very recently indeed my attention was called to a novel application of this fact by noticing some rather high

tensile tests of test-bars attached to some important castings made of a special bronze. The fracture of the test-pieces was exceedingly fine grained and showed an absolutely uniform or homogeneous structure. On examining very carefully some of the castings with the test-bars still attached, it was plainly to be seen that they were poured under very different conditions from the castings themselves, the test-bars being cast into iron molds so as to solidify them instantly, while the casting to which they were joined were made in ordinary sand molds.

Test-bars thus doctored are, in my judgment, far worse than useless, since they give the purchaser of the castings, who has taken the precaution (involving some trouble and expense) of turning and testing coupons, a false record of the character of the metal in his castings.

Apropos of this, I will venture, in conclusion, to refer to my short paper entitled "A Study of the Micro-Structure of Bronzes," printed in the JOURNAL OF THE FRANKLIN INSTITUTE, January, 1899, in which appear a number of photomicrographs of specimens of bronze metals (ninety were used in the investigation) cast in sand, and one representing a U. S. cent in which the crystals are very much finer and the metal is apparently more homogeneous, for there is an absence of the irregular bands of the eutectic alloy so conspicuous in all of the other bronze specimens. It was stated that: "This is perhaps partly owing to the fact that coin ingots are always cast in iron molds and the metal is thus suddenly solidified while all of the other specimens were cast in sand molds. This observation may have practical value."

The conclusions drawn from these investigations with bronze metals were quite similar to those already noted with respect to investigations in cast-iron, and are as follows:

1. Variations in treatment of specimens cause variations in the results, which may be misleading, and it would, therefore, seem desirable that some uniform system should be adopted by all investigators in this field.

2. The rate of cooling of a mass of metal affects the micro-structure so that two specimens from the same ladle of metal, one taken from a small casting quickly cooled, the other from a large casting slowly cooled; or two photomicrographs taken from different portions of the same specimen, may show variations in micro-structure that may lead to error.

It is desirable, therefore, that some uniform size of specimens (and uniform method of molding) should be selected by micro-metallurgists as a standard with which to make comparisons.

The actual case cited here, where bronze castings were made in sand molds subject to slow cooling, while the attached coupons for testing were made in iron molds to ensure rapid cooling, coming to my notice only a few days ago emphasizes the importance of some concerted action in accordance with the foregoing suggestions looking toward adoption of standard methods for testing metals, and for ensuring the integrity of such tests.

Numerous other illustrations might be drawn from my own daily experience and observation, but I think enough have been given to establish a good case. It is one that I have been arguing for a number of years.

Magnetic and Electrical Properties of Iron-Silicon Alloys. C. F. BURGESS and J. ASTON. (*Met. and Chem. Eng.*, 1910, viii.)—It was shown in 1901 that certain iron alloys made by Hadfield, containing 2¼ per cent. of aluminum or 2½ per cent. of silicon, had magnetic permeabilities exceeding that of pure iron. The authors have shown that similar results are obtained with irons containing 2 per cent. of tin or 4 per cent. of arsenic. The improvement in the magnetic qualities appears to be due to some change in the physical structure of the iron rather than to a chemical effect. Annealing at such a temperature as will remove the cooling and forging strains improves the entire magnetization curve of pure iron, while annealing at a high temperature deteriorates the quality with high and improves the permeability with low magnetizing forces. The authors investigated the magnetic properties of a number of iron-silicon alloys containing from 0.2 to 4.6 per cent. silicon, in comparison with a bar of very pure electrolytic iron. Unannealed, all fall below the standard bar, those containing the least silicon giving the best results. Annealing at 675° C. improved the results. Annealing at 1000° C. decreased the permeability of bars with low silicon, but improved bars of high silicon. The effect of silicon seems more pronounced in the presence of certain impurities. Silicon steels have a high electrical resistance which prevents eddy currents. With the addition of 4.66 per cent. silicon the alloy has a minimum hysteresis loss and an electrical resistance more than five times that of the electrolytic standard.

THE TEMPERATURE COEFFICIENT OF RESISTANCE OF COPPER.*

BY

J. H. DELLINGER.

THE values in common use for the temperature coefficient of copper vary from $a_0 = 0.00398$ to 0.00445, or $a_{20} = 0.00369$ to 0.00409 where a_0 and a_{20} are defined respectively by the equations: $R_t = R_o (1 + a_{ot})$, and $R_t = R_{20} (1 + a_{20} [t-20])$, in which t = any temperature Centigrade, and R_0, R_{20}, R_t = resistance respectively at 0° C., at 20° C., and at t° C. The differences in these various values assumed as standard may be considered to be due either to errors of the measurements made in establishing them, or to differences in the temperature coefficients of different samples of copper. In either case, accurate results cannot be expected when one of these values is taken as fixed and used for all samples. That this fact is not recognized is shown by the common practice of assuming that the temperature coefficient is the same for different samples of copper, while the conductivity is usually measured. It was accordingly considered of importance to determine whether the temperature coefficient of different samples does vary, and also to find whether there is any simple relation between the conductivity and the temperature coefficient.

This investigation has shown that there are variations of the temperature coefficient, and that to a fair accuracy the relation of conductivity to temperature coefficient is a simple proportionality. Thus, annealing is known to increase the conductivity of hard-drawn wire; it was found that annealing increases the temperature coefficient by an exactly proportionate amount. Samples varying in the amount of chemical impurities are known to vary in conductivity; it was found that the temperature coefficient was substantially proportional to the conductivity.

Samples were investigated from 14 of the most important copper refiners and wire manufacturers, in this country, Ger-

* Abstract of a paper to appear in Bulletin of the Bureau of Standards, vol. 7.

TABLE.

TEMPERATURE COEFFICIENTS (1) OBSERVED, AND (2) COMPUTED, FOR COPPER OF 100 PER CENT. CONDUCTIVITY.

* Percent conductivity	$\frac{a_{20}}{R_t - R_{20}} \div R_{20}[t-20]$	C $\left(= \frac{a_{20}}{\text{Percent conductivity}}\right)$	Mean values of C	Deviations from final mean
† 97.44	0.00384$_0$	0.00394$_1$		
† 97.46	0.00384$_3$	0.00394$_3$		
† 97.54	0.00384$_6$	0.00394$_3$		
100.22	0.00395$_0$	0.00394$_1$	0.00394$_2$	$+0_1$
100.24	0.00395$_2$	0.00394$_3$		
100.29	0.00395$_4$	0.00394$_3$		
100.44	0.00395$_9$	0.00394$_2$		
† 97.47	0.00382$_5$	0.00392$_4$	0.00392$_6$	-1_2
100.11	0.00393$_1$	0.00392$_7$		
99.96	0.00392$_7$	0.00392$_9$	0.00392$_7$	-1_1
100.09	0.00392$_9$	0.00392$_6$		
† 98.18	0.00386$_9$	0.00393$_2$	0.00393$_0$	-0_8
† 98.25	0.00386$_0$	0.00392$_9$		
99.73	0.00393$_8$	0.00394$_6$	0.00393$_8$	0_1
100.16	0.00393$_6$	0.00393$_0$		
† 96.56	0.00380$_6$	0.00394$_2$	0.00393$_7$	-0_1
† 96.96	0.00382$_8$	0.00394$_8$		
99.63	0.00391$_7$	0.00393$_2$		
99.97	0.00392$_7$	0.00392$_8$		
† 94.13	0.00371$_6$	0.00394$_8$	0.00394$_0$	$+1_1$
† 95.80	0.00378$_2$	0.00394$_8$		
96.60	0.00381$_8$	0.00394$_0$		
99.89	0.00394$_8$	0.00395$_0$		
† 97.07	0.00384$_9$	0.00395$_5$	0.00395$_2$	$+1_4$
99.75	0.00394$_0$	0.00395$_0$		
† 97.96	0.00385$_3$	0.00393$_2$	0.00393$_2$	-0_6
100.70	0.00395$_9$	0.00393$_2$		
99.14	0.00392$_6$	0.00396$_0$	0.00395$_6$	$+1_8$
99.39	0.00392$_8$	0.00395$_2$		
† 96.95	0.00383$_0$	0.00395$_9$	0.00394$_3$	$+0_5$
100.26	0.00394$_6$	0.00393$_6$		
† 97.84	0.00385$_0$	0.00393$_5$	0.00393$_2$	-0_6
100.54	0.00395$_1$	0.00393$_0$		
† 97.25	0.00382$_8$	0.00393$_6$	0.00393$_4$	-0_4
100.14	0.00393$_8$	0.00393$_2$		
† 97.75	0.00384$_5$	0.00393$_8$	0.00393$_1$	-0_7
100.70	0.00395$_7$	0.00392$_9$		
Final mean			0.00393$_8$	$=0_8$
Final mean rounded off			0.00394	$=0.2\%$

* 100% conductivity corresponds to resistivity of 0.153022 ohm per metregramme (or 1.72128 micro-ohms per centimetre cube, density = 8.89), at 20°C.
† Hard-drawn wires; the others are annealed.

many, France, and Austria. The range of conductivity of the samples covered thoroughly the range of the copper furnished to the electrical industry.

The experimental work was carried out with wires, most of which were No. 12, B. & S. gauge about 120 cm. long. The resistivity and percent conductivity were computed from measurements of the length, mass, and resistance The resistivity is given in "ohms per metre-gramme" by multiplying the resistance per metre by the mass per metre. The "percent conductivity" is calculated on the assumption that 100 percent conductivity corresponds to the arbitrary standard resistivity of 0.153022 ohm per metre-gramme at 20° C. The resistance measurements were made in a specially designed apparatus, by the Thomson bridge method. Temperatures were measured with a mercury-in-glass thermometer. The accuracy of the resulting conductivity values is estimated as within 0.03 per cent., and of the temperature coefficient values within 0.000004, or 0.1 per cent. To an accuracy of 0.2 per cent., the temperature coefficient was found to be linear between 10° C. and 100° C. The results of the measurements on the separate samples are given in the table above. For each sample, α_{20} is divided by the percent conductivity and the quotient given under *C*. *C*, the constant resulting, is the computed value of the temperature coefficient of copper of 100 percent conductivity.

The agreement of *C* for samples differing in physical condition is shown by the first and other groups. This agreement was further established by special annealing and drawing experiments.

The effect of bending and winding of wires was also investigated. Any distortion of an annealed wire is known to produce local hardening and increase of resistance. It was found that much the greater part of this increase was due to local changes of cross-section and not to the change of resistivity. This was shown by the fact that while the *apparent* conductivity decreased, the temperature coefficient changed practically not at all. This having been established for cases of bending and distortion more severe than those arising in ordinary practice, it may accordingly be assumed without serious error that the temperature coefficient of a copper wire is the same after winding on a machine or instrument as it was before. Accordingly, if a measurement

has been made of either the conductivity or the temperature coefficient of the wire before winding, the temperature coefficient may safely be assumed to be known after winding, and may be used in the calculation of temperature rise.

The main result of this investigation may be expressed in the form of the following practical rule: *The 20° C. temperature coefficient of a sample of copper is given by multiplying the number expressing the percent conductivity decimally by 0.00394.* The rule can be put in a remarkably convenient form for reducing the results of conductivity measurements to a standard temperature, viz.: *the change of the resistivity per degree C. of a sample of copper is 0.000598 ohm per metre-gramme or 0.00681 micro-ohm per centimetre cube.* The last two constants are independent both of the temperature of reference and of observation, and also independent of the sample of copper.

The foregoing results indicate that the measurement of conductivity may often be replaced by a measurement of the temperature coefficient. Four particular cases suggest themselves in which the measurement of temperature coefficient has considerable advantage over a conductivity measurement: (1) *Odd shapes.* Unless a uniform sample can be prepared, the determination of conductivity directly is hopeless. (2) *Short samples,* for which the difficulty of measurement of the dimensions and the possible uncertainty of the current distribution limit the applicability of conductivity measurement. (3) *Wires that have been distorted or bent.* As shown above, the apparent conductivity of a distorted wire is incorrect, while the temperature coefficient is not materially changed. (4) *The estimation of chemical purity,* of which the conductivity is a familiar criterion. Evidently the temperature coefficient is fully as reliable a criterion as the conductivity, and is more generally applicable, and is often an easier test to apply than either the conductivity or chemical determinations.

ATOMIC WEIGHTS—AN HISTORICAL SKETCH.

BY

JOSEPH SAMUEL HEPBURN, A.M., M.S.

[This paper reviews the fundamental laws underlying atomic weight determinations. A sketch is given of the work of Dalton, Berzelius and Stas upon these constants of nature. A description is given of the schools of chemists which have carried out atomic weight determinations at the University of Pennsylvania under E. F. Smith and at Harvard University under T. W. Richards.]

At the beginning of the nineteenth century, John Dalton[1] applied the ancient Greek philosophical theory of atoms,—the theory of Leucippus and Democritos,—as an explanation of his own laws of definite and multiple proportions, and thus founded the chemical atomic theory. Dalton then determined the 'relative' or atomic weights of the elements; in his "New System of Chemical Philosophy," Dalton took hydrogen as the unit with which he compared the other elements. He did not distinguish between atoms and molecules, hence his table contains atomic weights for water, ammonia and other compounds. Moreover Dalton had no means for ascertaining the number of atoms in a molecule, so he assumed that the atom (our molecule) of water consists of one atom of hydrogen and one atom of oxygen, whence the atomic weight of oxygen is given as 7, less than one-half of our value 16.

The study of atomic weights was aided greatly by the discovery of certain laws. In 1808 Gay Lussac and Humboldt deduced the law of combination by volume of gases. "When two or more gaseous substances combine to form a gaseous compound, the volumes of the individual constituents as well as their sum bear a simple relation to the volume of the compound,"[2] provided that the gases be under the same conditions of temperature and pressure. This law and the laws of Boyle and Charles have been used by Avogadro and Ampère,[3] and, later on, by Canizzaro as the basis of the molecular theory.

In 1819 Dulong and Petit announced the law of specific heats; the product of the specific heat of an element times its atomic

weight always gives approximately the same constant 6.25, *i.e.*, all the elements have approximately the same atomic heat. In 1831 Neumann and Regnault discovered that the molecular heat of a compound is a multiple of the atomic heat directly proportional to the number of atoms in the molecule, *e.g.*, lead chloride $PbCl_2$ contains 3 atoms in its molecule, and has a molecular heat of 18.45, about three times 6.25.

Mitscherlich deduced the law of isomorphism in 1819. "The same number of atoms combined in the same manner produce the same crystalline form, the latter being independent of the chemical nature of the atoms, and determined solely by their number and arrangement."[4] However barium permanganate and sodium sulphate are isomorphous in the sense that they possess the same crystalline form, yet they differ from each other in respect to the number of atoms in the molecule. Kopp[5] has found that compounds which have the same number of atoms, arranged in the same manner in the molecule and possess the same crystalline form,—isomorphous compounds according to Mitscherlich,—are characterized by the property of forming overgrowths, *e.g.*, a crystal of one alum will grow in the solution of another alum.

Within recent years, the Periodic Law of Lothar Meyer and Mendelejeff[6] has been helpful in determining the correct values of atomic weights. This law states that the properties of the elements are periodic functions of their atomic weights.

Berzelius devoted his life to atomic weight work; he made use of the laws of isomorphism, specific heats, and combination of gases by volume, and carried out analyses and syntheses without number; his work on atomic weights extended to many elements, including metals, non-metals and rare earths. As a standard atomic weight, Berzelius took oxygen equal to 100. His first table of atomic weights appeared in 1818; a revised table, which took into consideration the newly discovered laws, was issued in 1826. Many of the determinations of Berzelius, calculated to oxygen equals 16, compare favorably with the results of recent investigators.

The next great investigator to devote his life to atomic weight research was Jean Servais Stas, whose first work on the atomic weight of carbon appeared in 1841. His work on silver, sodium, potassium, lithium, lead, chlorine, bromine, iodine, sulphur, nitro-

gen and oxygen is classic. Stas was exceedingly careful in all his work, yet was guilty of errors in manipulation, for instance, he would drop dry sodium chloride into silver nitrate solution, and yet expect to obtain a precipitate of pure silver chloride free from occluded or included sodium chloride. In his earlier work, he neglected the solubility of silver chloride in water. In his investigations, Stas referred the halogens to silver. The task was undertaken to test the truth of Prout's hypothesis that the atomic weights of all the elements are simple multiples of hydrogen equal to one. Stas decided that this hypothesis is without foundation.

Stas died in 1890; the work on atomic weights has been continued in Europe by such men as Guye and Gutbier and in America by Keiser, J. P. Cooke, Mallet, E. F. Smith, and T. W. Richards.

During recent years a conflict has waged among chemists concerning the standards for atomic weights A few chemists led by Lothar Meyer have taken hydrogen equal to 1. The greater number of chemists have used oxygen equal to 16. Few of the elements form compounds with hydrogen and the ratio of an element *A* to hydrogen can usually be determined only by multiplying the ratio of *A* to a second element *B*, which most frequently is oxygen, by the ratio of *B* to hydrogen. Now the ratio of oxygen to hydrogen has been determined by various investigators and cannot be regarded as a fixed value. All the elements save fluorine and the members of the argon-helium group form oxides and hence allow a direct comparison between oxygen and the elements. Moreover if the ratio of an element to some element other than oxygen (say to silver or chlorine) be determined, the ratio of this second element to oxygen has been definitely determined. Oxygen equal to 16.00 has been accepted by the International Committee on Atomic Weights as the standard, and the column referred to hydrogen equal to 1 has been dropped from their reports since 1906.[7] However the United States Pharmacopœia still retains hydrogen equal to 1.000 as the standard.[8]

A new method for the determination of atomic weights was introduced by Smith and Maas[9] in a paper "Über das Atomgewicht von Molybdän." They heated a known weight of anhydrous sodium molybdate in a stream of hydrogen chloride gas,

weighed the residual sodium chloride and calculated the atomic weight of molybdenum. This work has been continued by E. F. Smith and his pupils at the University of Pennsylvania.

Hibbs [10] passed hydrogen chloride gas over heated potassium nitrate, weighed the residual potassium chloride and obtained the atomic weight of nitrogen. Sodium nitrate was treated in the same way for the same purpose. Sodium pyroarseniate, treated in this way, gave a value for the atomic weight of arsenic.

Lenher [11] treated silver selenite with hydrogen chloride gas, weighed the silver chloride formed, reduced the latter in hydrogen, weighed the metallic silver and thus obtained two values for the atomic weight of selenium.

Ebaugh [12] treated silver orthoarseniate with hydrogen chloride gas, weighed the silver chloride and then reduced the latter to metallic silver, which was weighed. This gave two values for the atomic weight of arsenic. Two more values were obtained by passing hydrogen chloride gas and hydrogen bromide gas over lead orthoarseniate, and weighing the residual lead chloride and lead bromide.

Friend and Smith [13] determined the atomic weight of antimony by treating potassium antimonyl tartrate with gaseous hydrogen chloride, and weighing the residual potassium chloride.

Smith and his pupils have devoted much time to the determination of the atomic weight of tungsten. In 1899 Hardin [14] stated that "So far as known, there is no perfectly reliable method for the determination of this constant. The method of reduction and oxidation is probably more accurate than any of the other methods which have been employed. The results obtained by it vary about one unit, and even more in exceptional cases." The story of the determination of the atomic weight of this element is a tale of the gradual elimination of impurities. Smith and Pennington took precautions to remove molybdic acid from their tungstic acid.[15] Schneider had noticed a very slight residue when purified tungstic acid was dissolved in aqueous potassium hydroxide, but neglected it. Taylor [16] found that purified tungstic acid, when treated with aqueous sodium carbonate, gave a white flocculent residue, which turned reddish-brown after standing in contact with the sodium carbonate solution for several hours. Exner and Smith [17] prepared ammonium paratungstate from wolframite of Lawrence County, South

Dakota. In the mother liquor they isolated ammonium vanadicophosphotungstate.[18] Hardin [19] had proved that tungstic acid obtained by ignition of ammonium tungstate contains nitrogen. Wyman [20] had experienced great difficulty in obtaining complete solution of tungstic acid in ammonia. Exner and Smith now examined the insoluble residues of Wyman and found them to contain ammonia and chlorine. To eliminate these impurities from tungstic acid, dry ammonium tungstate was thrown into pure boiling nitric acid, to which a small quantity of pure hydrochloric acid was added from time to time, and was digested for several hours. The tungstic acid thus obtained was thoroughly washed, suspended in water and dissolved by means of ammonia gas, in order to obtain ammonium paratungstate. This salt was submitted to fractional crystallization, and a product was finally obtained which did not give a precipitate on standing over night with sodium carbonate solution. Therefore this salt was free from those impurities which the investigators had striven to eliminate. The pure ammonium paratungstate was treated in porcelain vessels with nitric acid and a little hydrochloric acid, evaporated to dryness and ignited in order to obtain tungstic acid, which was reduced to metallic tungsten by the method of Hardin.[21] The tungsten metal was heated in chlorine gas to obtain tungsten hexachloride. A weighed quantity of the hexachloride was converted into the trioxide by means of water, aided by a very slight quantity of nitric acid. From the ratio of the trioxide and hexachloride, the atomic weight 184.04 was obtained for tungsten.

Hardin has applied electro-analysis in the determination of the atomic weights of mercury, silver and cadmium.[22]

A paper on atomic weights would be incomplete without reference to the work of T. W. Richards of Harvard and his pupils. Their work, which is found chiefly in the *Proceedings of the American Academy of Arts and Sciences* covers the atomic weights of copper, barium, strontium, zinc, magnesium, nickel, cobalt, iron, uranium, calcium, cæsium, potassium, sodium, iodine, chlorine, sulphur, arsenic, nitrogen, silver and chromium.

Richards and the Harvard school have worked chiefly on the halides of the metals, changing them to silver halide which is weighed. In connection with this work, the nephelometer was invented to measure the opalescence of silver chloride solu-

tions. A perfected form of nephelometer has been described by Richards and Wells.[23] Elaborate apparatus for fusing and bottling pure salts and metallic silver for atomic weight work had been devised by Richards and Parker.[24] "A Revision of the Atomic Weights of Sodium and Chlorine," [25] by Richards and Wells, shows in detail the manner in which Richards and his pupils attack a problem of this kind.

We thus see that the masters of the science for over a century have devoted their best efforts to determining these constants of nature. With the introduction of new and more accurate methods of analysis and of new methods for the purification of reagents, the old rule of Berzelius, which calls for the use of pure reagents and a simple method of analysis, is found to give accurate and concordant results.

REFERENCES.

[1] Ostwald's Klassiker der exakten Wissenschaften Nr. 3, Die Grundlagen der Atomtheorie, Abhandlungen von J. Dalton, 1–20.

[2] Remsen: Principles of Theoretical Chemistry, Fifth Edition, 34.

[3] Ostwald's Klassiker der exakten Wissenschaften Nr. 8, Die Grundlagen der Molekulartheorie, Abhandlungen von Avogadro und Ampère.

[4] Wurtz: Elements of Modern Chemistry, Fifth American Edition by Greene and Keller, 47.

[5] Kopp: Berichte der deutschen chemischen Gesellschaft, 1879, xii, 909.

[6] Ostwald's Klassiker der exakten Wissenschaften Nr. 68, Das natürliche System der chemischen Elemente, Abhandlungen von Lothar Meyer und D. Mendelejeff.

[7] Report of the International Committee on Atomic Weights, Journal of the American Chemical Society, 1906, xxviii, 1; 1907, xxix, 107; 1908, xxx, 1; 1909, xxxi, 1; 1910, xxxii, 1.

[8] Pharmacopœia of the United States of America, Eighth Decennial Revision, 596.

[9] Smith and Maas: Zeitschrift für anorganische Chemie, 1893, v, 280.

[10] Hibbs: University of Pennsylvania Thesis 1896.

[11] Lenher: University of Pennsylvania Thesis 1898.

[12] Ebaugh: University of Pennsylvania Thesis 1901, Journal of the American Chemical Society, 1902, xxiv, 489.

[13] Friend and Smith: Journal of the American Chemical Society, 1901, xxiii, 502.

[14] Hardin: Journal of the American Chemical Society, 1899, xxi, 1026.

[15] Pennington and Smith: Proceedings of the American Philosophical Society 1894, xxxiii, 332.

[16] Taylor: University of Pennsylvania Thesis 1901.

[17] Smith and Exner: Proceedings of the American Philosophical Society, 1904, xliii, 123.

[18] Smith and Exner: Journal of the American Chemical Society, 1902, xxiv, 573.
[19] Hardin: Journal of the American Chemical Society, 1897, xix, 675.
[20] Wyman: University of Pennsylvania Thesis 1902.
[21] Hardin: Journal of the American Chemical Society, 1897, xix, 667.
[22] Hardin: University of Pennsylvania Thesis 1896.
[23] Richards and Wells: American Chemical Journal, 1904, xxxi, 235; Wells: American Chemical Journal, 1906, xxxv, 99.
[24] Richards and Parker: Proceedings of the American Academy of Arts and Sciences, 1896, xxxii, 59, 63.
[25] Richards and Wells: A Revision of the Atomic Weights of Sodium and Chlorine, The Carnegie Institution of Washington, Publication No. 28, 1905.

Advantages of Enriched Air-Blast. J. W. RICHARDS. (*Met. Chem. Eng.*, viii, 123.)—The author discusses the combustion temperature attained in a blast-furnace and the methods used to raise it, with the increased efficiency resultant. He states that if the air be enriched with 5 per cent. of oxygen, the temperature of combustion is increased 370° over that attained by un-enriched air. It is estimated that the capacity of the furnace would be increased one-third; and that the velocity of the gases would be decreased on account of the smaller volume of nitrogen. The average temperature of the furnace would be lower, thus decreasing the loss by radiation, and the escaping gases would be richer in combustibles and therefore better fuel gas. The fuel economy is estimated at about one-sixth.

Prevention of the Formation of Coal-dust. (*Engineering*, lxxxix, 678, 2317.)—The sprinkling of coal with water, to prevent dust explosions is not popular either with owners or colliers. It has to be frequently repeated, the atmosphere becomes damp, and the mine muddy, and it requires much labor. The Kruskopf process substitutes a paste for water. Coal which dried in 6 hours when sprinkled, remained damp 3000 hours when treated with this paste. Comparative experiments showed that a dynamite charge of 5 Gm. produced a coal-dust explosion, but when the coal was treated with paste, twelve successive charges of 160 Gm. failed to produce an explosion.

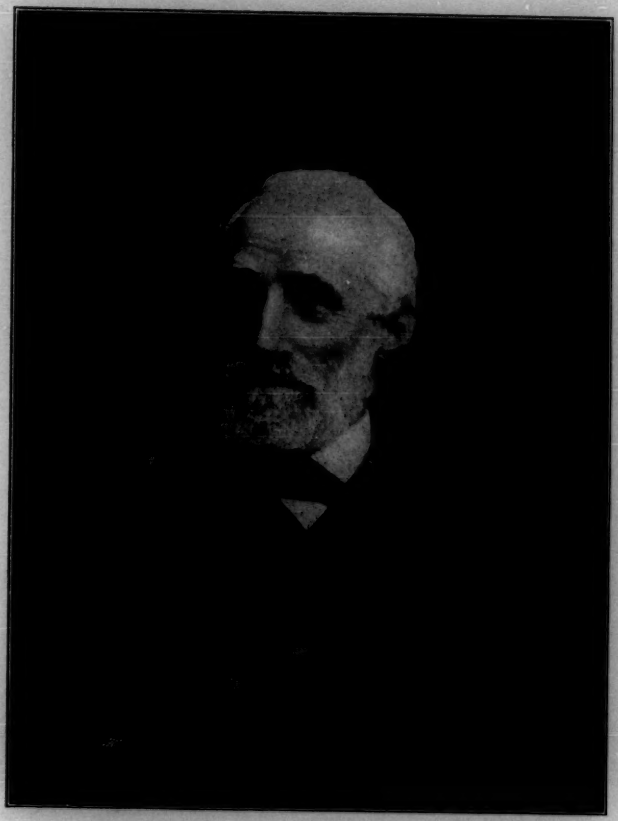
IN MEMORIAM.

Washington Jones.

Washington Jones, the venerable third Vice-President of the Franklin Institute, passed away on 30th July, ult., in the eighty-eighth year of his age. He was the son of Thomas J. and Eliza (Ranstead) Jones, born in Philadelphia February 22, 1822, and educated in the common school of his native city. Entering the employ of Merrick & Agnew as an apprentice in the Southwark Foundry in 1838, Mr. Jones retained his connection with that noted establishment and its various offshoots throughout more than a half-century thereafter. From 1838 to 1844 he studied under private tutors to acquire a mastery of his calling, and succeeded so well as to be accorded the post of Chief draftsman of the Penn Marine Engine Works in 1849, advancing to that of Superintendent of the Port Richmond Iron Works in 1856, Asst. Superintendent of the Southwark Foundry from 1861 to 1866 and General Superintendent and Constructing Engineer of the Port Richmond Iron Works from 1866 to 1891.

From that time on, Mr. Jones gradually retired from the forefront of industrial activity, but only to widen the scope of his interests in the field wherein he had helped to accomplish the great advances of the past two generations. He was director of the American Dredging Co.; a member of the American Society of Civil Engineers; member and past president of the Engineers' Club of Philadelphia; member of the Society of Naval Architecture and Marine Engineers; member of the American Institute of Mining Engineers and the Philadelphia Association for the Relief of Disabled Firemen.

At the time of his death Mr. Jones was the oldest surviving member of the Franklin Institute, having joined on January 21, 1847, and became a life member in 1853. He was elected to the Board of Managers in January, 1859; for many years he was one of the curators of the Institute and since 1902 served as Vice-President. His attendance at the meetings of the Board continued with scarce an intermission to the beginning of this summer's recess, and now that he is gone, the well-known figure of this valiant veteran of the mechanic arts, with his wealth of shimmering white hair wreathing his genial and kindly countenance, will long be held in pleasant memory by his associates.



Washington Jones

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LIBRARY NOTES.

Purchases.

LEHMANN, O.—"Molekularphysik," 2 vols.

HÜBL, A. VON.—"Three-color Photography."

ABRAHAM, M.—"Elektromagnetische Theorie der Strahlung."

AMSTUTZ, N. S.—"Hand-book of Photo-engraving."

SMITH, F.—"The Stone Ages in North Britain and Ireland."

CHURCH, I. P.—"Hydraulic Motors."

KAYSER, H.—"Handbuch der Spectroscopie." Band 5.

International Catalogue of Scientific Literature: Seventh annual issue,—D. Chemisty. Eight annual issue,—A. Mathematics; B. Mechanics; G. Mineralogy; J. Geography.

BRILLOUIN, M.—Leçons sur la viscosite des liquids et des gaz."

BOUASSE, H.—"Cours de physique." 6 vols.

Résumés des Brevets d'Invention déposés en France. Année 1901, Acétylène, Automobilisme, Piles et Accumulateurs. 3 parts.

Gifts.

Abhandlungen der Kaiserlichen Leopoldinisch-Carolinischen Deutschen Akademie der Naturforscher. Band 90 and 91. Halle, 1909. (From the Academy.)

Statistics of Railways in the United States. Twenty-first annual report of the Inter-State Commerce Commission. Washington, 1909. (From the Commission.)

Graphic Arts and Crafts Year-Book, 1910. Hamilton, Ohio. (From Mr. Max Levy.)

Celestial Ejectamenta. By Henry Wilde. Oxford, 1910. (From the Author.)

Philadelphia College of Physicians, Transactions, vol. 31. Philadelphia, 1909. (From the College.)

American Iron and Steel Association, Statistical Report. Philadelphia, 1910. (From the Association.)

Massachusetts Board of Education, Seventy-third Report. Boston, 1910. (From the Board.)

Yale University Astronomical Observatory, Transactions. Vol. 2, part 2. New Haven, 1910. (From the Observatory.)

Metropolitan Sewerage Commission of New York, Report. New York, 1910. (From the Commission.)

American Society of Heating and Ventilating Engineers, Transactions. Vol. 14. New York, 1908. (From the Society.)

Newton (Mass.) Public Documents. Newton, 1910. (From the City Clerk.)

Commonwealth of Australia, Official Year-Book, 1901–1909. Melbourne, 1910. (From the Commonwealth Statistician.)

Queensland Under-Secretary for Mines, Report. Brisbane, 1910. (From the Secretary of Mines.)

PUBLICATIONS RECEIVED.

La Métallographie microscopique par Louis Révillon, Ingenieur des Arts et Manufactures. Encyclopedie Scientifique des Aide-Mémoire. 176 pages, illustrations, 12mo. Paris, Gauthier-Villars, n.d.

Notions élémentaires sur la probabilité des erreurs par Maurice d'Ocagne, Ingénieur en chef des ponts et chaussées, Professeur a l'École des ponts et chausées. 26 pages, illustrations, 8vo. Paris, Gauthier-Villars, 1910.

Link-Belt Company. "Link-Belt" coal tipples, retarding conveyors, car hauls and coal washeries. Booklet No. 95, revised 1910. 42 pages, illustrations, 8vo. Phila., Link-Belt Co.

Solid Bitumens, their physical and chemical properties and chemical analysis, together with a treatise on the chemical technology of bituminous pavements. By S. F. Peckham, A.M. 324 pages, illustrations, 8vo. New York, Myron C. Clark Pub. Co., 1909.

Handbuch der Telephonie. Nach dem manuskripte des Dr. Victor Wietlisbach, weiland technischer direktor des Schweizer telephonwesens in Bern. Bearbeitet von Dr. Robert Weber, professor der Physik an der Akademie in Neuchatel. Zweite auflage bearbeitet von Ingenieur Johannes Zacharias. 468 pages, illustrations, 8vo. Wien, Hartleben, 1910.

Statistik der Knappschaftsvereine des preussischen Staates im Jahre 1908. Nach amtlichen Quellen bearbeitet. Sonderdruck aus der Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate, Jahrgang, 1909 (Band 57). 73 pages, quarto. Berlin, W. Ernst & Son, 1909.

Canada Department of Mines. Summary report of the mines branch for the calendar year ending December 31, 1909. 181 pages, illustrations, 8vo. Ottawa, King's Printer, 1910.

Link-Belt Company. General price-list and Catalogue No. 90. 400 pages, illustrations, 8vo. Chicago, 1910.

Metzograph Grained Screen (Wheeler's patent), its application to block-making, photolithography and photogravure. 18 pages, illustrations, 8vo. London, A. W. Penrose & Co.

Canada, Department of Mines, Mines Branch. Bulletin No. 2. Iron Ore Deposits of the Bristol Mine, Pontiac County, Que., Magnetometric Survey, etc. By E. Lindeman, M.E. Magnetic Concentration of Ores. By George C. Mackenzie, B.Sc. 15 pages, illustrations, maps, 8vo. Ottawa, Government Printing Bureau, 1910.

Carnegie Library of Pittsburg. Technical indexes and bibliographies appearing serially. Reprinted from the Monthly Bulletin, June 1910. 17 pages, 8vo. Pittsburg, Carnegie Library, 1910.

Second International Congress of Refrigeration, Vienna, Austria, October 9–12, 1910. Announcement, program of meetings, etc. Chicago, American Association of Refrigeration, 1910.

North Carolina Geological and Economic Survey. Bulletin No. 18. Bibliography of North Carolina Geology, Mineralogy and Geography with a list of maps. By Francis Baker Laney, Ph.D., Assistant Curator of Geology in the U. S. National Museum and Katharine Hill Wood. 428 pages, 8vo. Raleigh, State Printer, 1909.

Allen's Commercial Organic Analysis. A treatise on the properties, modes of assaying, and proximate analytical examination of the various organic chemicals and products employed in the arts, manufactures, medicine, etc. Vol. iii, Hydrocarbons, Bitumens, etc., 4th edition, entirely rewritten. Edited by W. A. Davis, B.Sc., A.C.G.I., and Samuel S. Sadtler, S.B. Philadelphia, P. Blakiston's Son and Co., 1910.

Kurze übersicht über sämtliche Legierungen. Von Dr. Ernst Jänecke, privatdozent an der technischen Hochschule in Hanover. 100 pages, illustrations, 8vo. Hanover, Dr. Max Jänecke, 1910.

University of Illinois Bulletin, vol. 7, No. 2. Chemical and biological survey of the waters of Illinois. Report for year ending December 31, 1908. Edward Bartow, director. Water survey series, No. 7. 204 pages, illustrations, 8vo. Urbana, University.

Engineering Record directory of manufacturers of and dealers in engineers' and contractors' machinery and supplies, 3rd edition, 131 pages, 16mo. New York, Engineering Record, 1910.

Illuminating Engineering Society. Transactions, March, 1910, vol. 5, No. 3. Easton, Society.

Comments on Professor Swain's article on floods and forests (in American Forestry, April, 1910). By Thomas P. Roberts, United States Engineer's Office, Pittsburg, Penna. 5 pages, 8vo. Reprinted from Monthly Weather Review, 1910, 38, 496–498.

Georgia Geological Survey, Bulletin No. 24. A second report on the public roads of Georgia. By S. W. McCallie, State Geologist. 37 pages, 8vo. Atlanta, State Printer, 1910.

Zoological Bulletin of the division of zoology of the Pennsylvania department of agriculture. Vol 7, Nos. 11 and 12. Subjects: Bee-keeping, nursery inspection report, index to volume 7. April and May 1910. H. A. Surface, M.S., Economic Entomologist, editor. Harrisburg, State Printer, 1910.

Anregungen zur Organisation industrieller Betriebe. Von Ingenieur Dr. Robert Grimshaw. Uebersetzung eines von demselben Verfasser vor dem Franklin Institut, Philadelphia, gehaltenen Vortrages. Nach "Organisation, Fachblatt für leitende Männer in Handel und Industrie" gedruckt. 46 pages, 16mo. Hanover, Dr. Max Jänecke, n. d.

BOOK NOTICES.

DER KONSTRUKTIONSTAHL UND SEINE MIKROSTRUKTUR. Von A. Hænig, Ingenieur. 360 illustrations, 8vo. Berlin, M. Krayn, 1910. Price, in paper, 15 marks.

The author presents the fifth volume of the Technical Automobile Library under the above caption. She also gives in an appendix "The Micrographic Researches Upon the Structural Components of Quenched Steel"—the work of M. Breuil.

In the introduction this volume treats of allotropism; over-cooling and under-cooling; the practical taking of cooling curves; the crystallization of salt-water solutions; the laws of melting and freezing points; the eutectic; the diagram of Roberts-Austin; that of Roozeboom; and constructions of the phase rule.

In the second part under the head of "Considerations of Special Steels Chiefly for Automobile Manufacturing" a review is made of the ternery steels such as nickel steel, chrome steel, tungsten steel, and vanadium steel; the quarternery steels such as chrome-nickel steel, chrome-vanadium steel, and nickel-vanadium steel; and of the composition of special automobile steels of the trade together with their microstructure and classification.

The third part treats of "Practical Metallography" in which the instruments manufactured by various firms on the Continent, preparation of test specimens, development of structure of various means, such as etching with divers reagents, and combined polishing and etching, the preparation of photographs including the developing and fixing of plates, are elaborated.

The appendix contains a series of photographs showing the structure of steels of various carbon contents beginning with 1.80 per cent. carbon and continuing to wrought-iron. It also contains photomicrographs of cast-iron with about 4.25 per cent. carbon. These photomicrographs show the structures resulting after a great variety of treatments. They are interesting and well reproduced; but of doubtful value to the automobile engineer.

The data contained in this volume has been compiled from the publications of the Alloys Research Committee; the various papers of Leon Guillet; Osmond; Ed. Maurer; Breuil; Dr. Rudolph Ruer; Martens; Heyn; and P. Goerens; and such journals as *The Iron and Steel Institute; Revue De Metallurgie; Metallurgie; Stahl und Eisen;* and the trade catalogues of the various iron and steel manufacturers of Europe.

Like most German compilations, the work seems to have been completely and thoroughly done. The illustrations are excellent; and naturally those illustrating the Krupp products are the most numerous and prominent. Mention is made of some steels manufactured by the Bethlehem Steel Company; and reference is made to the paper of John A. Matthews read for the Franklin Institute, April, 1909. No further mention is made of American contributions to the knowledge of Automobile Steels, or of firms manufacturing Automobile Steels in America.

G. W. S.

CURRENT TOPICS

Transport Phenomena in Solutions of Coloring Matters. LEO VIGNON. (*Comptes rendus*, cl, 923.)—Experiments on the electrolysis of solutions of dyes have shown that transport phenomena are well marked with those substances which form colloidal solutions but are absent in the case of dyes forming true solutions.

Simple Apparatus for Determining Melting Points. THEODOR WEYL. (*Chem. Zeit.*, xxxiv, 488.)—A thermometer is slightly expanded just above the bulb. A glass ring loosely fitting the thermometer stem rests on the expansion; it carries glass hooks placed vertically in pairs which serve to hold the melting point tubes in position close to the bulb. This obviates the use of india rubber rings or platinum wire for attaching the tubes to the thermometer.

The Photo-chemical Decomposition of Silver Halides. A. P. H. TRAVELLI. (*Chem. Woekblad.*, vii, 404.)—Ostwald's law supports the theory that the decomposition of silver halides into silver and halogen is attended by the intermediate production of silver sub-halides, and is opposed to the view that colloidal silver is formed directly from silver halides. These substances have the power of forming photo-chemical sub-halides only when in the solid state and not in the liquid state, but silver halides in solution are reduced by chemical "developers" to sub-halides. The presence of alkaline halides or ammonia induces reduction to metallic silver. The chemical "developer" may be regarded as a special solvent for the silver halide, the polymeric form of which goes into solution as a complex anion. Of the sub-halides the green variety is most sensitive to light, the red least, while the blue occupies an intermediate position.

The Ionization of Various Gases by the β-rays of Actinium. R. D. KLEEMAN. (*Proc. Royal Socy., A.*, 83, 530.)—The relative ionizations produced by the β-rays of actinium and uranium respectively in air, hydrogen, ethyl ether, ethyl chloride, ethyl bromide and ethyl iodide are the same. The β-rays of actinium, being of much lower velocity than those of uranium, it follows that the relative atomic absorptions and ionization are independent of the velocity of the rays for atoms up to the atomic weight of iodine.

Radio-active Recoil. SIDNEY RUSS. (*Le Radium*, vii, 93.)—The decay curves of the recoil products collected on a disc suspended 7 cm. above the bottom of an exhausted glass tube, on which radium

emanation is kept condensed by liquid air, agree well with the view that the number of atoms of *radium-A* and of *radium-B* recoiled are equal, but that of *radium-C* only a relatively very small number of atoms are recoiled. Since the first two substances both result in α-ray changes, whilst the third results in a change in which no α-ray but only slow β-rays are expelled, this is as is to be expected.

Use and Abuse of the Ionic Theory. G. N. LEWIS. (*Science*, xxx, 1.)—A criticism of the ionic theory in which attention is called to the common error of applying laws and methods to concentrated solutions, which are of such a character as to be applicable only to highly dilute solutions; to the danger of deducing too much from the additive properties of salt solutions; to the abnormal behavior of hydrogen ions and hydroxyl ions in water with the analogous high velocity of methylate ions in methyl alcohol; and lastly to the complete breakdown of the law of mass-action when applied to strong electrolytes.

Action of Light on Dyes. KURT GEBHARD. (*Zeit. Angew. Chem.*, xxiii, 820.)—The author confirms the theory that the bleaching of dye solutions or of dyed tissues by light is due to the primary formation of a peroxide of the dye. The peroxide is best detected by acidified potassium iodide and starch, by alkaline potassium permanganate, or by diphenylamine and concentrated sulphuric acid; chromic, molybdic and titanic acids do not indicate the presence of a peroxide; this fact forms one argument of several against the theory of the primary formation of hydrogen peroxide. The most effective rays are those complementary to the color of the dye. Blue, violet and ultra-violet rays exert a decomposing action on the peroxide, or occasion a transference of the active oxygen to unattacked molecules of the dye.

Corrosion of Metals. (*Eng. Record*, lxi, 26.)—The Institute of Metals, of Great Britain, has appointed a committee to investigate the corrosion of metals other than iron and steel. Many manufacturers and users of non-ferrous metals have experienced many troubles on account of the corrosion of these alloys, particularly in marine work and power plants on the sea-coast. The results of such corrosion are frequently of such a serious nature as to make the investigation by the Institute a matter for congratulation among engineers.

The Carbo Process for Open-Hearth Steel. (*Iron Age*, lxxxv, 26.)—This modification has been developed by Louis M. Atha, Newark, N. J. Its object is to reduce the percentage or entirely eliminate the use of pig iron. The essential feature of the process is the introduction of "Carbo" into the furnace; *i.e.*, oil-retort carbon. This carbon is pulverized. It is very hard and re-

mains in the charge while melting down for a much longer time than other carbon. It is therefore absorbed and not carried off by the vapors. In working the open-hearth furnace, limestone or other suitable flux is introduced, then the steel and iron scrap, then the pulverized carbon and on top of this the pig- or cast-iron. The whole is melted down and the product is a fine grade of steel. "Carbo" is about 90 per cent. pure carbon and is extremely slow burning. The lime charge can be reduced when carbo is used and it is said that the value of the lime saved will about pay for the carbo. This reduction in lime allows the heat to be worked a little faster, thus reducing the fuel cost per ton and increasing the weekly production of the furnace.

Iron Ore in Northern Ontario. (*The Iron Age*, lxxxv, 26.)—It is reported that iron ore deposits have been found at Grand Rapids, on the Mattagami River, which is a tributary of the Moose River. The ore deposits are about 60 miles south of Moose Factory, and about 100 miles north of the National Transcontinental Railway and from the Temis Kaming & Northern Ontario Railway. These deposits have been known for some time. They were discovered in 1875 by Dr. Robert Bell of the Canadian Geological Survey; and were again noticed in 1903 by a party making explorations for the Ontario Bureau of Mines. The Bureau's report for 1904 contains a description of the deposits, which are classed as of the limonite variety of ore. The ore body is very large and the metallic iron found is sometimes as much as 60 per cent., containing only about 0.08 per cent. of phosphorus. Parties who have staked claims are very optimistic both as to the quantity and quality of the ore, which they consider to be brown hematite.

The Last of the Lake Whalebacks. (*Iron Age*, lxxxv, 26.)—The whalebacks proved unsatisfactory in the lake ore-carrying trade, as their peculiar shape made it impossible to use modern unloading machinery. Out of seven boats belonging to the Great Lakes Engineering Works, Detroit, only four have been operated this season. It is said the owners will dispose of all of them. Many of the original whaleback fleet have been used in the coal trade or as oil barges on the Atlantic Coast.

Strength of Steel in I-beams. E. L. HANCOCK. (*Eng. Record*, lxii, 2.)—This paper was read before the American Society for testing materials. It gives curves for the variation of the elastic limit and for stress deformation, with micro-photographs of test pieces. The conclusions reached are: (1) The elastic limit varies considerably for material cut from different portions of the beam, both standard and Bethlehem, being lowest in root of web, higher in flange near root, and highest in web. This confirms the work

of Prof. Marburg. (2) The indications are that there is a considerable difference chemically in the material in different parts of the beam. (3) The appearance of the fractured pieces indicates a considerable variation in the density of the material throughout the beam, due probably to the work of rolling. The thin beams show material superior to that of the thick beams.

The Influence of Titanium on Segregation in Bessemer Rail-Steel. G. B. WATERHOUSE. (*Eng. Record*, lxii, 2.)—The tests were made on ingots of rail-steel and ingots of similar steel to which 0.25 per cent. of titanium had been added during the pouring. There was no trace of the titanium in the steel with which it was used, but there was a marked increase in the soundness of the steel on account of the concentration of the blow-holes in the pipe cavity. A great number of drillings were taken from the ingots and analyses showed the effect of the titanium was to reduce the segregation of the sulphur, phosphorus and carbon; the results of the silicon and manganese determinations were too erratic for presentation, but they did not show segregation.

Intrinsic Brightness of Stars. C. NORDMANN. (*Comptes rendus*, cl, 669.)—As an extension of the application of Planck's law an attempt is made to determine the intrinsic brightness of certain stars by estimating the wave-length of the maximum brightness of their spectra. A table of results is given, showing that the order of effective brilliancy is in agreement with that of temperature gradation.

Cementation of Silicon Steels. LOUIS GRENET. (*Comptes rendus*, cl, 921.)—Silicon steels which do not undergo cementation under ordinary conditions when heated in charcoal, readily do so when the operation is carried out with potassium ferrocyanide.

Rotary Engine. (*Iron Age*, lxxxv, 23.)—The Herrick Engine Co. has announced the invention of its rotary engine. Hitherto none of the rotary engines invented have been successfully operated for any reasonable length of time. In this case an important new principle has been discovered, that of balancing unequal lateral thrusts on the rotor shaft of any rotary engine having but a single blade, and some other defects have been overcome.

Specific Heat and Heat of Solidification of Pig-Iron. W. SCHMIDT. (*Metal*, vii, 164.)—Swedish pig-iron was fused in a carbon crucible and introduced into an ice calorimeter, the temperature being measured by a thermocouple. Experiments were made at 1375°, 1275°, 1175°, and 1130° C.; in the last case the metal was introduced into the calorimeter immediately after solidification. Analysis showed the carbon content to be about

4.3 per cent. which corresponds closely to the composition of the eutectic. The results show that the specific heat of iron between 1175° and 1275° C. is 0.3136 and between 1275° and 1375° C. is 0.3216. Assuming that at 1130° C. the specific heat of iron is 0.31, the heat of solidification of white pig-iron of the eutectic composition is 59 calories per gramme.

Heroult Electric Furnaces. (*Iron Age,* lxxxv, 23.)—The Rombacher Huettenwerke have installed two Heroult electric furnaces, which are to be followed by four more of 12 tons each. The Heroult furnaces installed at the Deutscher Kaiser Stahlwerke at Bruchhausen, Germany, have commenced refining steel, and the results both in quality of product and moderate cost of operation are reported to be more than satisfactory.

Extrusion of Metals in the Solid State. (*Iron Age,* lxxxv, 25.)—An article on the extrusion of those metals which can not be readily drawn, *e.g.,* zinc, aluminum, copper, etc., which will be found very interesting and of value.

Constitution of Portland Cement. CLIFFORD RICHARDSON. (*Eng. Record,* lxii, 3.)—A most interesting and instructive article that will well repay perusal. It is strange that the users of Portland Cement know so little of its composition, which is probably due to the fact that the later researches into this material have only been made public in scientific journals which are seldom brought to the notice of engineers.

A Mono-rail Line. (*Eng. Record,* lxii, 4.)—Such a line, 3 miles long, was recently completed in the Bronx, New York City. On the first regular trip, when carrying 100 passengers, the supporting structure failed and the passengers were badly shaken. The car is 50 feet long and 6½ feet wide, with seats for 50 passengers. It runs on a single rail, and is supported above by guide rails, engaging wheels on top of the car. These guide rails carry the 550-volt direct current for operating.

Titanium in Making Steel Rails.—(*English Mining Journal,* lxxxviii 1066.)—The use of titanium in making Bessemer steel for rails is becoming general. The method is to use ferrotitanium which combines readily with steel and purifies and improves its physical properties. The alloy is employed as a flux for cleaning iron and steel at the moment of casting or pouring from the converter. Sulphur and phosphorus are not reduced, but titanium in combining with oxygen and nitrogen form oxide and nitride. Titanium removes impurities, forming a stable combination which passes into the flux. The principal function of the titanium alloy is to act as a flux and the cleansing effect results in increased

solidity and purity, which have an important influence on the mechanical structure of the steel, preventing breaking down under heavy rolling loads and reducing the wear due to abrasion, which are serious defects in ordinary Bessemer steels. Ferrotitanium contains 10 to 15 per cent. titanium, 5 to 7 per cent. carbon and less than 5 per cent. of other impurities, the remainder is pure electrolytic iron. In Bessemer steel manufacture 1 per cent. of crushed ferrotitanium is added to the ladle as the steel is poured from the converter.

Corrosion of Structural Steel. (*Eng. Record*, lxii, 5.)—In bridges and in buildings that are exposed to the action of various corrosive elements, the disintegration of steel is so rapid, or the cost of protection is so large, that there is great need of some satisfactory preventative treatment. The electrolytic theory of corrosion seems to be based on sound principles and it is to be hoped that the interest now felt on the subject will not be allowed to decrease. Concrete is generally considered to be a good protective coating.

The Trans-Andine Railroad Completed. (*Iron Age*, lxxxv, 11.)—This is the first transcontinental railroad completed in South America. It reduces the time between Valparaiso and Buenos Aires to 29 hours; formerly the overland journey occupied a week, and the journey by water, through the Straits of Magellan, took from 10 to 14 days. The total distance is 880 miles. The principal difficulties were encountered in one stretch of 13 miles at a high altitude in the Cordilleras. In these 13 miles are 15 tunnels, some of them short, but the one under the Cumbre Pass is 2 miles long. Some of these tunnels are straight, but most are curved and some wind around in a corkscrew manner.

Emergency Electric Lights for Ships.—The steamship *Alabama* of the Goodrich Line, which runs between Chicago and Muskegon, Mich., has recently installed an interesting system of emergency electric lights which is furnished with current from a storage battery.

These lights have been installed to provide illumination in the corridors and on stairways in case of an accident to the generating apparatus, or, in case of the sinking of the vessel, lights would be available to aid passengers in making their escape even after the hull of the boat had sunk some distance in the water.

In order to provide illumination as long as possible in case the boat should sink, the battery has been placed at the highest point of one of the upper decks.

The storage battery in use is composed of 56 cells type ET "Chloride Accumulator" in glass jars, manufactured by The Electric Storage Battery Co., having a rated output of 4.5 amperes

for 8 hours. This battery will supply current for 10 hours on one charge for 25 4-candlepower 110-volt carbon lamps which are in use in this installation.

The battery is charged during the day, and at night after the generators stop running, the lights used on decks, in halls and stairways are supplied with current from the battery alone. This system provides a reliable source of lighting which is always available in case of accident.

Similar battery equipments installed on other boats for furnishing current for emergency electric lighting service are also extensively used for the operation of wireless telegraph apparatus.

A New Resistor Furnace. F. A. J. FITZGERALD. (*Met. and Chem. Eng.*, viii, 317.)—Experiments have been made in a zinc smelting works in Upper Silesia, Germany, with a 150 kilowatt furnace in which the charge in the crucible is heated by radiation from an electrical resistor. By building the furnace with double walls, bottom, and cover, and burning fuel in the space thus formed, so as to keep the temperature therein approximately the same as that of the working chamber, it is stated to be possible to almost completely prevent loss of electrically generated heat, and to expect very great economies, especially in large furnaces. Furnaces of this type have been run continuously for nearly two months, and they may be allowed to cool repeatedly without having to be repaired. They are suitable for many other metallurgical operations besides zinc smelting.

Brown Stain for Wood. Patented by C. BUNNENBURG, Germany.—A concentrated ammoniacal solution of cupric oxide is mixed with four times its weight of a 4 per cent. solution of potassium bichromate. This mixture is said to impart a grayish-brown color to oak smilar to that of old wood.

Action of Hydrogen on Platinum and Nickel Wire. M. VON PIRANI and A. R. MEYER. (*Z. elektrochem.*, xvi, 444.)—When nickel and platinum are heated to a high temperature in a current of hydrogen they undergo a permanent change. The nickel shows an increase of electrical resistance, the platinum, a lowering of the melting point and reduced ductility. This is apparently not due to the occlusion of hydrogen, but to the absorption of carbon from small quantities of accidental organic impurities carried by the gas.

Colloidal Metals. C. SERONO. (*Arch. Farmacol. Sperim.*, ix, 152.)—If an electric current be passed through a five per cent. solution of purified gelatin, rendered conductive by the addition of 1 per cent. of sodium chloride or sulphate, a colloidal solution of the cathode metal is obtained in about 10 minutes in the vicinity of the anode. With a gold cathode, the colloidal solution contains 42

mgm. of the metal per litre, and with a silver cathode, 87 mgm. per litre. An iron cathode yields a solution of ferrous sulphate, small quantities of ferrous hydroxide, and colloidal, non-dialyzable iron. The colloidal solutions are stable, contain no submicroscopic particles, and remain sterile. When a porous earthenware diaphragm is used, no trace of colloidal metal is found in the cathode compartment. These colloidal solutions are suitable for medicinal purposes when diluted.

Composition of Lime-Sulphur Spray. H. V. TARTAR and C. E. BRADLEY. (*J. Ind. Eng. Chem.*, ii, 271.)—The lime-sulphur solution, obtained by boiling together slaked lime and sulphur, which is used for spraying trees as an insecticide and a fungicide, was investigated both as to its composition and as to the chemical changes which the spray undergoes when used. The authors find that the chief constituents are calcium tetrasulphide and pentasulphide, but that these compounds are so readily converted into the more stable disulphide, with liberation of sulphur, that this excess sulphur might almost be considered as being merely in physical solution. Small quantities of thiosulphate, and traces of sulphite and sulphate, are also present. Free calcium hydroxide, and the monosulphide and the hydrosulphide appear to be absent. When the solution is sprayed on trees, the carbonic acid in the air acts upon it and liberates hydrogen sulphide and sulphur, but only to a small extent. The deposition of sulphur is almost entirely due to oxidation on the one hand, and to the mere evaporation of the solution on the other.

Open-Hearth Furnaces. TERPITZ. (*Stahl und Eisen*, xxx, 1029.)—The author considers from his experience that the effects produced on the products of the open-hearth furnace usually attributed to an excess of hydrogen in the heating gases, are not due to the gas itself but to the superheating of the charge due to the excess. Nitrogen also is not believed to be injurious, since the appearances supposed to be due to this gas are really the effect of the treatment in the subsequent stages. It is only in most rare cases that sulphur is absorbed by the steel. The only gases that have any influence are those produced in the bath by the oxidation and reduction reactions; the slag protects the metal from the heating gases. The effect of hydrogen on the sides of the furnace is discussed, and its effect is attributed to its high calorific value.

Gases in Steel. P. HÉROULT. (*Met. and Chem. Eng.*, viii. 332.)—In opposition to the view that the amount of gases occluded in steel depends on the opportunities presented to the metal of absorbing them in the process of manufacture, the author states that repeated experiments have shown that the quantities of gases liberated, on placing the metal in a vacuum chamber, are approximately

the same from steels made by the Bessemer, basic, and acid open-hearth, crucible and electric processes respectively. Blow-holes, except when due to faulty moulds, are considered to be the result of liberation of carbon monoxide by the reaction of carbon and ferrous oxide in the steel. When molten steel has partly solidified, the carbon and ferrous oxide become concentrated in the portion remaining liquid, the condition of equilibrium is disturbed, and carbon monoxide is evolved, the blow-hole thus produced being filled with this gas at a high temperature. On further cooling, the pressure in the holes is diminished, and nitrogen and hydrogen are drawn into the holes from the surrounding metal, in the same way as those gases are disengaged when a piece of the solid metal is placed in a vacuum chamber. In conclusion it is stated that the small quantity of gases which may be present in steel are not injurious or detrimental to the quality of the metal.

The Coefficient of Equivalence in Special Zinc Bronzes. L. GUILLET and L. RÈVILLON. (*Rev. Métal.*, vii, 429.)—It was found that when part of the tin was replaced by zinc, the metallographical estimation, based on the area of the δ-constituent, indicated a content of tin higher than that found by analysis. The coefficient of equivalence of zinc was then estimated, but was found to be less than 0.1, showing that the effect of the addition of zinc was quite small. Zinc does not act by replacing one of the elements in the alloy, but dissolves in the copper without sensibly modifying the solubility of tin in the copper. For quantities of zinc up to 30 per cent., the alloys have similar mechanical properties to the corresponding alloys free from zinc, except that the solid solution free from zinc is harder than that containing zinc.

Separating Complex Ores, or their Concentrates. W. M. MARTIN, England.—Mr. Martin has patented a process for this separation by the use of sodium nitrate. Complex lead-zinc ores or concentrates are crushed and well moistened with a solution of an oxidizing agent, such as sodium nitrate, and the mass heated to dull redness for a few minutes. The ore is then crushed and the constituents separated by ordinary water concentration. About 2 per cent. of sodium nitrate is necessary for a crude ore, and a correspondingly larger quantity for a concentrate or an equivalent quantity of dry sodium nitrate thoroughly incorporated with the ore may be substituted for the solution.

The Antiseptic Properties of Copper. A. SPRINGER and A. SPRINGER JUN. (*Chem. Zeit.*, xxxiv, 585.)—Milk, suspected of containing antiseptics, was found to contain small quantities of copper (about 4 mgm. per litre). Its presence is ascribed to the wearing off of the tin coating on the copper utensils, and to the brass fittings in the dairy. Milk containing copper is remarkable for retain-

ing its sweet odor even when quite curdled; finally when covered with mould, it has a nut-like aroma free from any putrefactive odor. Milk which became sour in 10–12 days, in sealed bottles in an ice chest, kept for 22–24 days if one part of copper was added to 250,000 of milk. The authors conclude that copper salts should be useful remedies in the intestines in cases of diseases characterized by increase of the number of putrefactive bacilli.

Quick-drying Ink. Patented by A. RUETER, France.—An addition is made to the ink of a neutral, volatile substance such as alcohol or a similar material, in the proportion of one part to five of the ink.

Zinc Oxychlorides. DRIOT. (*Comptes rendus*, cl, 1426.)—Two oxychlorides were obtained by the action of zinc oxide on zinc chloride solutions, viz., $ZnCl_2,4ZnO,6H_2O$ and $ZnCl_2,ZnO,1.5.H_2O$. The first is a white amorphous body which loses 5 molecules of H_2O at 200° C., but the last molecule is only driven off at a high temperature together with hydrochloric acid and zinc chloride. The second oxychloride is a microscopically crystalline body, losing one molecule of water at 230° C. and the remainder at a very high temperature, along with hydrochloric acid. To prepare these bodies the precipitated zinc oxide must be left in contact with the zinc chloride solution for several months, removing the solid mass from time to time to pulverize it. They are dried by suction and then by pressing between porous plates and filter paper. With the exception of the first of these bodies, which had been previously discovered, no indications were obtained of the eight oxychlorides found by previous experimenters.

Action of Heat on Carbon Monoxide. A. GAUTIER. (*Comptes rendus*, cl, 1383.)—Carbon monoxide was circulated through a porcelain tube heated to temperature ranging from 820° to 1300° C. and having an inner tube of glass which was cooled by a rapid current of cold water. Small quantities of moisture and carbon dioxide were formed, possibly due to the hydrogen present in the CO to the extent of 0.21 per cent. No trace of carbon or other deposit was observed. The author concludes that, at a temperature of 1300° C. under ordinary pressure, in porcelain tubes and in the absence of organic matter and metals, carbon monoxide undergoes no appreciable dissociation, and no carbon is set free.

Purification of Argon and Nitrogen. F. FISCHER and O. HAEHNEL. (*Ber.*, xliii, 1435.)—To remove possible traces of air and nitrogen from argon it is passed over red hot calcium. The apparatus is practically the same as that used by the authors for preparing argon, except that there is no external connection to the air; and that, for the vessel containing calcium carbide, there is substituted an iron tube containing metallic calcium, which is heated

in a combustion furnace. The portions of the iron tube which project from the furnaces are water-jacketed, and the corks are surrounded by jackets filled with mercury, so as to preclude all possibility of the entrance of air. All the glass stop-cocks in the apparatus are also provided with mercury joints, both at their upper and lower extremities, as are also the stoppers of the gas-holders. The whole apparatus, except the gas-holder containing the argon, is exhausted by the Toepler pump, and the circulation is then set up by the automatic rise and fall of the mercury in the circulating pump, and continued as long as desired. The density of the purified argon was found to be 19.945. Nitrogen, circulated over heated metallic copper, had a density of 14.018. A bright glow was visible in the apparatus during the circulation of argon, but not with nitrogen.

Corrosion of Iron and Steel. PROF. E. HEYN. (*Iron Age*, lxxxvi, 2.)—Steel, wrought-iron and cast-iron do not show notable differences in the attack of rust in still water, but such differences do appear in flowing water. Cast-iron is then attacked more vigorously than wrought-iron or steel. This is offset by the fact that in flowing water steel is attacked in a very irregular manner, so that in the same sample certain spots are attacked but little, while other spots are much corroded. With cast-iron the attack is considerably more uniform. The degree of the attack by rust of steel and cast-iron is dependent upon the speed of flow of the water. With increasing speed of flow the attack increases at first to decline again when the maximum is passed. In a strongly agitated solution of salt, the differences in the degree of attack of steel, wrought-iron and cast-iron decrease.

Formaldehyde in Foods. G. PERRIER. (*Rev. Soc. hyg. alim.*, v, 804.)—The author points out that extremely minute quantities of formaldehyde can be detected in foods by modern methods. Many food products, like smoked meats, contain traces of it, absorbed from wood smoke. A strict interpretation of the law would prohibit the sale of these foods, which is obviously not intended by the law-makers. It would therefore be better, instead of absolutely prohibiting formaldehyde, to establish a maximum limit for it. Formaldehyde was detected in smoked sausage, ham, red herrings, etc.

New Process for Softening Calcareous Water. (*Rev. gen. mat. color.*, xiv, 98.)—This process, invented by Gans, depends on the use of permutite, a double basic aluminum silicate, made by fusing kaolin, quartz, and sodium carbonate. It reduces the hardness of calcareous water to zero, and it can be recovered and converted into its original condition by the use of a suitable salt, so that it can be re-used indefinitely. An iron cylinder is used,

with a layer of sand top and bottom and a layer of permutite between. The thickness of the permutite layer is proportional to the speed of filtration and the hardness of the water. The regeneration of the permutite is effected by pumping through it a 15 to 20 per cent. solution of sodium chloride (salt). This process has been adopted by several German and French chemical factories.

Water Disinfection. (*Engineering News*, xlii, 309.)—The use of bleaching powder, or calcium hypochlorite, as a disinfectant is called the most interesting and important recent advance in water purification. Special attention is called to the use of calcium hypochlorite as an aid to filtration and to the growing tendency toward decreasing the burden on filters.

Lithographic Stones in Greece.—Deposits of these stones were found three or four miles from Pharsala, in Thessaly, comprising nearly 5000 acres. The quantity is estimated at 35,000,000 cubic feet; at one point the thickness of the layers of lithographic stone was 20 feet. The thickness of the flags is generally one-half to one and one-half inches, occasionally reaching two inches. A layer of red clay divides the flags. For the most part the stone is of the pearl-gray variety, but there is a small proportion of white stone, worth double the value of the pearl-gray stone. Pieces of three to six square feet area, without any defect, are quite common, while some reach the enormous size of 13 to 16 square feet.

Nickel Wire. (*Engineering News.*)—The use of nickel wire for electric furnaces is not preferred to platinum, although it is cheaper, because nickel becomes brittle when exposed to high temperature. Professor H. C. H. Carpenter found this brittleness was partly due to the gradual escape of the occluded gases. On the other hand, Prof. M. Le Blanc, of Leipzig, found nickel wire suitable in experiments in which the furnaces were heated to 1300° C., and Nernst mentioned, during a discussion in the Deutsche Bunsen Gesellschaft, that he wound his nickel wire on a copper tube (instead of clay or porcelain) and insulated the copper with asbestos and sodium silicate; while the wire itself was finally coated with a mixture of sodium silicate and soapstone.

Barium in Blast-Furnace Slag. R. H. SWEETSER. (*Iron Age*, lxxxv, 5.)—When the silica in a blast-furnace slag goes below 30 per cent. and the sum of silica and alumina is below 43 per cent. there is danger of a "lime-set" in the furnace, or at least some very low silicon iron, and the composition of the slag should be changed. Such slags are hard to manage and require too much coke per ton of pig-iron to be economical. But when such a slag is found to be easy running, and requires little coke per ton of pig, it requires further investigation. Such a condition existed in

a furnace making Bessemer iron, with a mixture that yielded 57.4 per cent. pig-iron and required only 714 pounds of limestone per ton of pig. The slag gradually dropped to 28.90 per cent. of silica, but the furnace worked smoothly. Evidently there was an unusual constituent in the slag. A full analysis gave:

	Per cent.		Per cent.
FeO	0.40	CaO	45.10
SiO_2	29.15	MgO	5.10
Al_2O_3	13.40	BaO	2.45
		S	1.85

Here was a slag with 52.65 per cent. of bases and only 42.65 per cent. of silica and alumina, yet very fluid, and "white hot" while running and did not slack when cold. It was concluded that the barium oxide was the cause of the lower melting temperature.

Prof. H. O. Hofman has published a chart showing the effects of BaO and MgO in slags formed in lead and copper furnaces, and probably their influence would be the same in iron blast-furnace slags as in slags of non-ferrous metals. Briefly he shows that MgO raises the temperature curve while BaO lowers it, and therefore BaO is a powerful flux, and promotes the slagging of MgO. A slag having a formation temperature of 1150° C., was lowered to 985° C. when three-fourths of the CaO was replaced by BaO, and even when all the CaO was removed the temperature rose only to 1010° C. BaO also lowers the melting points of other refractory oxides.

The First Steam-Turbine Locomotive. (*Iron Age*, lxxxv, 11.)—The new type of steam-turbine electric locomotive, where a turbine of the impulse type is directly coupled to a direct-current variable-voltage dynamo, has been completed at the works of the North British Locomotive Co., Glasgow, Scotland. It is stated that the tests were very satisfactory and confirmed the theoretical claims of its designers.

Natural Zirconium Oxide. (*Berichte*, 1910, 43.)—Large quantities of natural zirconium dioxide are found in the Minas Geraes district of Brazil, and the material is cheaper than zircon ($ZrSiO_4$) which was until recently the main source of zirconium compounds. There are three qualities of the natural zirconium dioxide, namely (1) black, glassy, kidney-shaped pieces; (2) broken, stony fragments; and (3) pebbles. The glassy variety has an olive green or brownish surface and breaks under the hammer to wedge shaped pieces; between these a brownish-yellow powdery mass occurs which contains all the iron, and can be mechanically removed. After its removal the residue contains almost 98 per cent. of zirconium dioxide; the black color is probably due to titanium. Its specific gravity is 5.41.

Photographs of the Flight of Shot. F. NEESEN. (*Phys. Zeitschr.*, x, 968)—The great height which balloon artillery must be able to reach necessitates an extension of the range-tables, hence photographic reproductions of the flight of projectiles are of particular interest, although they give no information as to velocity. Two photographs are included in the paper, one showing the path of a smoke-producing projectile, the other showing the end of the flight of five luminous projectiles from a mountain gun, taken in twilight. This is much clearer than that of the smoke shot and the paths of several shot can be shown on the same plate.

The Chemistry of Steam Boilers. (*La Nature*, No. 1922.)—We have frequently warned our readers of the inconveniences and even of the dangers in the use of water heavily charged with lime salts in steam boilers. To prevent the presence of this excess of lime salts in the water used for steam boilers, their treatment with various salts has been recommended, such as sodium carbonate or sodium sulphate or with lime. Basch, a German author, states that when sodium carbonate is used, any excess of it is partially decomposed into sodium oxide and carbonic acid—this decomposition does not commence until the temperature exceeds 160° C. He has also shown that the reaction between sodium sulphate and the calcium carbonate in the water is reversible,—

$$Na_2SO_4 + CaCO_3 \leftrightharpoons Na_2CO_3 + CaSO_4$$

and that therefore an equilibrium may be established between these substances, which prevents a complete purification of the water.

Steel Balls as Burnishers. (*Amer. Mach.*, xxxiii, 16.)—Any small metal parts can be quickly and effectually burnished by placing the work in a horizontal tumbling barrel, made of wood to avoid scratching the work, together with a large quantity of small steel balls, in bulk about twice that of the work to be burnished, together with a mild soap mixture, and then rotating the barrel. The time required for the work varies inversely to the quantity of balls and directly to the size of the balls. This process takes the place of buffing, both before and after plating. The balls range from ⅛ inch to ¼ inch. Their cost, in reasonable quantity, is about 30 cents per pound.

Ammonia from Nitrogen and Hydrogen. F. HABER. (*Zeit. Electrochem.*, 1910, xvi.)—At 200 atmospheres pressure, and in presence of suitable contact substances, nitrogen and hydrogen combine to form ammonia in sufficient quantity for practical processes. The reaction is incomplete and the ammonia must be removed as it is formed, which is done by a system of circulation of the gases at high pressure. The ammonia is condensed and removed either as gas or as anhydrous liquid, the uncombined gases continue to cir-

culate through the system. Osmium is the most active contact material, and as a fine powder, at 175 atmospheres pressure and a temperature of 550° C., a yield of 8 volumes per cent. is obtained from the mixed gases. As osmium is scarce, uranium, containing a certain amount of carbide, or carbon, may be substituted. This is transformed to a very fine powder which absorbs nitrogen and exercises a powerful catalytic action on the gaseous mixture at a temperature below 500° C. The power necessary for compression and circulation of the reacting gases is very small.

Cotton Bleaching. E. JUSTIN MUELLER. (*Bulletin Soc. Ind. Mulhouse,* 1909, lxxix.)—In a comparison of the material turned out from a number of bleach works, the author concludes that the most important factor in the removal of the dressing or size is the duration of the lye-boil. Different methods of bleaching, properly carried out, yield practically equally good results. An acid-steep, in dilute sulphuric or hydrochloric acid, does not appear to be very efficacious. The most efficient and rapid agent for the destruction of the starch is diastofor.

Rendering Fibres Inflammable. A. CHAPLET. (*Rev. Gen. Mat. Col.,* 1910, xiv.)—This is effected by the fixation of insoluble magnesium-ammonium phosphate in the fibre. The materials are padded in a concentrated solution of a soluble phosphate, preferably the mono-calcium salt, and are then passed through an ammoniacal solution of magnesium chloride. Magnesium ammonium phosphate is thus precipitated on and in the fibre, and after rinsing in very dilute ammonia and drying, the material is practically non-inflammable. This property is only slightly affected by rubbing or washing.

Carbon Bisulphide. F. KOREF. (*Zeit. Anorg. Chem.,* 1910, lxvi.) Equilibrium in the formation of carbon bisulphide from solid carbon and gaseous sulphur has been studied at various temperatures between 800° and 1100° C., and the equilibrium constants obtained, both by the formation and dissociation of the substance. In each case the gas concerned was passed at varying rates through a heated tube, and equilibrium was assumed to be reached when the constant remained unaltered at different rates. Carbon bisulphide is found to be an exothermic compound, its heat of formation being 12,500 calories. The negative heat of formation observed by previous workers using solid sulphur is probably due to the very large heat of vaporization of sulphur.

Action of Ozone on Carbon Monoxide. P. CLAUSMANN. (*Comptes rendus,* cl, 1332.)—Clean glass tubes were filled with a mixture of ozonized oxygen (200 mgm. ozone per litre) and carbon monoxide. These gases were prepared separately and well purified,

then mixed in the tubes, which were sealed and exposed to light, when the gases were dried, by means of phosphorus pentoxide, and mixed in equal volumes, 2.83 parts of carbon dioxide were formed per 100 parts of total oxygen in 8 days; under the same conditions, but in the dark, only 0.88 part of carbon dioxide was formed. With the gases not dried and exposed to the light 3.67 parts of carbon dioxide were formed in one day.

Liquid- and Gas-Tight Joints. C. S. BEDFORD and F. ATKINS. (*Jour. Soc. of Chem. Ind.*, xxix, 7.)—A composition that is claimed for making tight joints in the screw-cap stoppers of vessels for the storage of petroleum, benzol, etc., consists of gelatin 40 parts, glycerin 42 parts, pigment 2 parts, water 15 parts. The composition is made into sheets, or spread upon a suitable fabric, from which discs or gaskets may be cut for making the joints.

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